Bulletin No. 241

Series { D, Petrography and Mineralogy, 31
B, Chemistry and Physics, 43

DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

EXPERIMENTS

ON

SCHISTOSITY AND SLATY CLEAVAGE

BY

GEORGE F. BECKER

WASHINGTON
GOVERNMENT PRINTING OFFICE
1904

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DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., June 4, 1904.

SIR: I have the honor to transmit herewith a paper by myself describing experiments made for the purpose of testing disputed theories of schistosity and slaty cleavage.

Very respectfully,

GEORGE F. BECKER,
Geologist in Charge Division of Chemical and Physical Research.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

EXPERIMENTS ON SCHISTOSITY AND SLATY CLEAVAGE.

By George F. Becker.

Abundance of fissile rocks.—A very large part of the rocks exposed at the earth's surface exhibit schistosity or cleavability not ascribable to sedimentation and often well marked in masses of igneous origin. In many cases the surfaces along which rocks cleave intersect one another, producing a foliated structure. In other instances the cleavage occurs in nearly parallel planes or along surfaces having large radii of curvature. None of these phenomena are confined to highly indurated rocks, as might be inferred from some discussions, but are found well developed in soft and fragile unmetamorphosed shales, as all who have made observations in disturbed Tertiary areas are aware. Specimens of these shales are so fragile, however, that they are scantily represented in collections. Slaty cleavage, as the term is used in this paper, means simply the most regular and extreme form of cleavability or schistosity, in which the laminæ are thin and are bounded by substantially parallel surfaces, no matter whether the material exhibiting these properties is indurated, as in the valuable roofing slates, or is soft and fragile, as in the comparatively worthless shales. Though argillaceous rocks exhibit the most perfect cleavage, this does not apparently differ in kind from the schistosity sometimes found in grit beds, limestone, granite, quartzite, and basic eruptives. A structure which is at least analogous is found in rolled or drawn metals, in terra-cotta articles, such as roofing tiles, and in pastry.[a] In short, slaty cleavage is a structure, or a group of structures not readily distinguishable from one another, and has a character of its own independent of the material which may exhibit it, although some substances are better fitted than others to display it in perfection. This relationship is recognized in the French term "schiste," which, in Gallic usage, comprehends shales, slates, and the crystalline schists of English writers. In English usage schist is commonly synonymous with crystalline schist, but the frequent use of this adjective would seem to imply the existence of schists which are not crystalline, and these could hardly be defined otherwise than as equivalent to shales.

[a] Cf. Daubrée, A., Géol. Exp., pp. 398 and 428.

Slaty cleavage, even in highly indurated rock, passes over by insensible gradations into less simple forms of schistosity, and vast masses of the crystalline schists show cleavage planes in systems intersecting one another at acute angles. It has always seemed to me that a true explanation of cleavage must include the theory of foliated schists as well as of roofing slate. The association of mica with cleavable rocks has often been insisted upon, perhaps with too great emphasis. Some shales contain much mica, but others contain only a little. According to Professor Rosenbusch, shales (Schieferthone) have the same mineralogical composition as clays, and mica is not an essential constituent. Sorby mentions clay slates which carry very little mica, and G. W. Hawes[a] describes a roofing slate from Littleton, N. H., which on microscopic examination is found to consist of fragments of quartz and feldspar as fine as dust, although in the larger part of the rocks called clay slate in New Hampshire he found abundant mica. Now clay slates and some shales have as good cleavage as mica-schists. Again, quartz-schists and other cleavable rocks contain very little mica. The grit beds or sandy strata found in slates do not always contain much mica, and yet their cleavage is manifestly of the same origin as that of the slate in which they are embedded. It is well known that near intrusive masses mica-schist not infrequently passes over into ordinary schists, and these into phyllites and clay slates, as if the amount of mica were characteristic of the degree of metamorphism rather than an index of the cleavability. "Compression," says Sir Archibald Geikie, "may give rise to slaty cleavage. But it has often been accompanied or followed by further internal transformations in the rocks. Chemical reactions have been set up and new minerals have been formed." In the study of slates it is often manifest that a portion of the mica is secondary. Thus on blind joints (Ausweichungsclivage of Heim) large continuous sheets of mica are frequently found. Muscovite is also well known to be one of the chief decomposition products of the feldspars, an alteration which is readily intelligible from a chemical standpoint. The increase of the mica content of phyllites as compared with shales seems to me most reasonably accounted for as a concomitant of the genesis of cleavage, though not an essential one.

Importance of cleavage.—Schistosity as a structure is important, and it is a part of the business of geologists to explain its origin. Slaty cleavage has further and greater importance as a possible tectonic feature. Scarcely a great mountain range exists, or has existed, along the course of which belts of slaty rock are not found, the dip of the cleavage usually approaching verticality. Are these slate belts equivalent to minutely distributed step faults of great total throw, or do they indicate compression perpendicular to the cleavage without attendant

[a] Hitchcock, C. H., Geology of New Hampshire, vol. 3, 1878, pt. 4, pp. 237, 238.

relative dislocation? Evidently the answer to this question is of first importance in the interpretation of orogenic phenomena.

Theories of cleavage.—The earliest theory of slaty cleavage assimilated it to mineral cleavage, a view not tenable after microscopic study. Mr. John Phillips in 1843 was the first to interpret slaty cleavage as an effect of mechanical strain. Mr. Daniel Sharpe in 1849 offered the explanation now most generally accepted by geologists, viz, that a fracture perpendicular to the line of pressure would run along the flattest faces of the component grains and meet the smallest number of them—a theory implying that the mass is heterogeneous and that the adhesion between the component particles is smaller than the cohesion within the particles. Dr. H. C. Sorby later described a variety of cleavage due to the presence of numerous microscopic blind joints.[a] Professor Tyndall in 1856 made exceedingly interesting experiments on this subject, obtaining admirable cleavage in wax. He denied that heterogeneity aided cleavage. In his first paper he asserted most emphatically that the cleavage was perpendicular to the direction of pressure, but in a footnote and in a later paper he indicated decided doubt as to this perpendicularity. Professor Daubrée (1879) also dissented from the view that heterogeneity is essential to slaty cleavage, and ascribed this structure to gliding ("glissement," slide) in the mass, which is equivalent to a denial of the perpendicularity of the causative force to the consequent cleavage.[b] In 1893 I published a theory founded on experiment and analysis. It is in agreement with Daubrée's idea, but more precise. According to this theory, cleavage is due to a weakening of cohesion[c] along planes of maximum tangential strain (or maximum slide). It is susceptible of proof[d] that deformation due to pressure is actually effected by relative motion of the mass in opposite directions parallel to these planes. When this movement exceeds the elastic limit and falls short of the breaking strain, it would seem inevi-

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[a] Sorby's theory of slate was that the preliminary effect of pressure on argillaceous strata is to give the mica an irregular distribution, and the final effect to rearrange the mica in new parallel planes. This hypothesis is still accepted in some text-books. To me it appears too fanciful for serious discussion. If mica scales, in all possible orientations, were to be mingled with mud, their average inclination to any plane would be 32° 42′ (or the well-known "average latitude of all places north of the equator"). If such a mass were to be compressed until the average angle were only 2° to a given plane, the thickness of the mass must be reduced to one-eighteenth. If a sediment containing mica were to be treated according to Sorby's theory, it would seemingly be needful to press it at first in such a way as to increase its thickness some eighteen times and then to compress it again in another direction to about its original thickness.

The attempt has been made to account for the cleavage surfaces on Sorby's hypothesis as maximum cleavability. I can not concur in this view. The cleavage in slate is confined within very narrow limits, perhaps one degree. Slate may be broken indeed at greater inclinations, but the ruptured surfaces do not then show imperfect cleavage; they are conchoidal or irregular and destitute of cleavage.

[b] The reader will find a digest of the literature in Mr. Alfred Harker's memoir on slaty cleavage, Brit. Assoc., 1885, p. 813, and some further notes in my paper on finite homogeneous strain, flow, and rupture of rocks, Bull. Geol. Soc. America, vol. 4, 1893, pp. 75-87.

[c] As H. Rogers put it, "the cohesive force is obviously at a minimum of intensity in the direction perpendicular to these planes" of cleavage. Trans. Royal Soc., Edinburgh, vol. 21, 1857, p. 450.

[d] See note on the theory of slaty cleavage appended to this paper.

table that the cohesion should be diminished and that cleavage should result.[a] Only in ideally brittle substances is there no interval between the elastic limit and the breaking strain. It is of course certain that the material constituting slate has been strained far beyond its elastic limit; and that it has a breaking strain is often manifested by blind joints. These planes stand at an angle of 45° or more to the direction of greatest local linear compression. There are at least two sets of them, and maybe four, symmetrically disposed with reference to this direction. In cases of double cleavage—so usual in disturbed areas, both in distinct development and in the more or less irregular form of ordinary schistosity and foliation—cleavage is produced on both sets of planes, so that a cross section shows acute-angled rhombs somewhat like those indicated in fig. 13, Pl. III, and in fig. 30, Pl. VI. In the case of forces acting on a supported mass at an acute angle to the plane of support, it was shown in my paper that the effect of viscosity would be to suppress all but one set of cleavages and to accentuate this remaining one. Tyndall's experiment, properly considered, was shown to be a case of this kind, and it was maintained that the cleavage of roofing slate is thus to be explained. If this be true, a belt of slate is equivalent to a great fault distributed over an infinite number of infinitesimal steps.[b]

Distinction between Sharpe's theory and mine.—The distinction between Sharpe's theory and mine is well defined. If in any portion of the mass before strain a small sphere is supposed to be marked out, this sphere after strain will have become an ellipsoid, called the strain ellipsoid. If Sharpe's theory is correct, the cleavage due to pressure will be in surfaces perpendicular to the smallest axis of the strain ellipsoid. If my theory is correct, the cleavage will make with this smallest axis an acute angle equal to or greater than 45°, and increasing as the strain grows greater.

Means of studying the strain ellipsoid.—The general nature of the experiments needed to compare the theories is made plain by this contrast. It amounts to a study of the strain ellipsoid. One means to this end is to incorporate into a mass to be experimented upon small spheres of the same material as the remainder, but of a distinguishable color. After straining is effected dissection or rupture, by exposing the distorted sphere, will show the local character of the strain and the posi-

[a] A pertinent illustration of weakening of cohesion is afforded by bars of mild steel ruptured by tension. The most plausible a priori idea of rupture by tension is that it would occur in a plane perpendicular to the line of force; and in hard steels this mode of rupture is often observed. In mild steels, on the other hand, the surface of rupture is rough and granular, the grains approaching pyramidal forms. The aggregate surface of such a fracture is far in excess of that of the mean plane. Now, since the rupture must follow a surface of least resistance, the resistance per unit area on the pyramidal faces must have been much smaller than that on the plane surface perpendicular to the tension. This can be due only to a weakening of cohesion along the pyramidal faces.

[b] This theory embraces rupture as well as simple and double or multiple cleavage. So far as jointing and cleavage due to blind joints are concerned, it has been accepted by some geologists, who regard true cleavage as a distinct phenomenon.

tions of the axes of the strain ellipsoid. Numerous experiments of this description have been made for this paper, and some of them are illustrated in fig. 2, Pl. II. They are instructive, but not sufficiently so. If it were practicable to build up an adequate block of small spheres and to fill in the interstices uniformly with the same material differently colored, the mass after strain would show the character of the strain ellipsoid at uniformly spaced intervals. This is impracticable, but the result sought can be attained very approximately in another way. If a block of material be pierced with fine holes at regular intervals, forming in one plane a network of small squares such as is shown in fig. 5, Pl. II, and the holes be filled with coloring matter, then strain, followed by dissection, will show the figures into which the small squares have been distorted. If the squares were very small, the sides of the distorted figures would be nearly straight and parallel. It would then be easy by a geometrical construction to inscribe ellipses tangent to the four sides at their middle points, and these ellipses would accurately represent the section of the strain ellipsoid. Even if the sides were somewhat curved, the strain at the center of the curvilinear parallelogram would be very closely represented by an ellipse found by a rational system of interpolation, as will be described in a note appended to this paper. Experiments have been made in this way also, the distorted figures being photographed and photographically enlarged to a convenient scale for constructing the ellipses.

Linear compression.—Experiments by Tyndall's method are very simply and easily executed, but the resulting strain is highly complex and indeed could not be discussed as a problem of pure mechanics in the present state of knowledge of the transmission of energy in plastic bodies. By the means noted in the last paragraph such experiments can be sufficiently elucidated for an investigation of slaty cleavage.

Rolling.—Another known means of producing slaty cleavage is by rolling out a cake of suitable material as a cook prepares pastry, or by passing the mass between rolls. It is easy to prick holes perpendicular to the surface of the cake before rolling, fill them with pigment, and, after distortion, to dissect the mass. The nature of the effect is seen in fig. 4 of Pl. II, the originally vertical lines being drawn out into parabola-like curves which are vertical only at the apex. Cleavage may be developed especially near the upper and lower surfaces of the rolled mass, to which it is nearly parallel. Such experiments, however, give results which are less definite and less easily discussed than those given by Tyndall's method. The manner of applying the force and the degree of rolling affect the result, as a matter of course; and it seems difficult to establish a standard of conditions.

Scission engine.—It is evidently most desirable to make experiments by producing simple well-known strains which will or may lead to cleavage. For this purpose I designed what may be called a "scission

engine," a simple mechanism, shown without its cover in fig. 1, Pl. I. A block of material to be experimented upon is placed in the space B, the cover (provided with grooves to receive PP) is put on, screwed down onto pillars, and the driving screw set in motion. The bars F H revolve round the fixed pivots F, and the hinges H bend while the plates PP slide in their own planes. The area and volume of the space B remain constant and the strain produced is approximately a scission (or shearing motion). On four of the six faces, however, there is friction, which interferes somewhat, but not seriously, with the perfection of the strain.[a] If a circle is inscribed on the upper surface of the block before strain, it becomes approximately an ellipse showing the orientation of the strain ellipsoid. When the space B is thoroughly filled, no rupture within the mass is possible, the finite movement being distributed over an infinite number of planes; but if the space is not filled, complex strains result and rupture may occur. The engine gives about the unit strain, or produces a block with two angles of 45°.

Ceresin and its treatment.—The experiments to be described have been made principally with ceresin and a smooth clay such as is used by sculptors for modeling. I have tried white wax, which was the material employed by Tyndall, but white ceresin is preferable. This substance is refined ozocerite and consists of a mixture of paraffins. The material at my disposal melts at about 60° C., but some of the component paraffins solidify at a higher temperature, so that at 60° the cooling melt is a pasty mass, like thick oatmeal gruel. It contracts greatly in solidifying and should be cast at as low a temperature as practicable to prevent radial crystallization. Shavings of the solidified mass under the microscope show brilliant polarization colors, so that the mass is a crystalline solid. A particle fused on a slide and allowed to cool also shows high double refraction and exhibits a hypidiomorphic structure, analogous to that of semiporphyritic granites of excessively fine grain. Castings chilled in ice and salt and then broken with a hammer display a very fine-grained granular structure and somewhat conchoidal fracture, with no apparent radial crystallization.

The strong analogy between this solid and a rock is deserving of special emphasis. I can not see how deformations in masses of ceresin can possibly differ in character from those in the vastly less tractable crystalline rocks.

In carrying out Tyndall's experiment with ceresin I cast cylinders about 1½ inches in diameter and nearly 2 inches in length. After the cylinders were cold the ends were planed down until all trace of the pit due to contraction was removed. Before compressing them they remained in a thermostat for some hours at 35°, because at considerably lower temperatures they rupture or crumble too easily. Com-

[a] To obviate in some measure the effect of friction toward the center of the block, I made the space B 6 cm. long and only 4 cm. wide.

SCISSION ENGINE.

pression was effected in a copying press between two heavy glass plates mounted on boards. To avoid superficial chilling of the ceresin cylinders the glass plates were warmed to approximately the same temperature as the ceresin. Good cleavage is not obtained unless the cylinders are reduced to one-third of the original length, and more nearly perfect cleavage results from still further reduction. For accurate study the compressive force should be applied to the cylinders so slowly as not to rupture the edges of the cakes by tension. The compressed cakes were placed in a mixture of ice and salt for an hour or two, and then, being held edgewise on a small anvil, were broken by striking smart blows on the edge with a light hammer.

It is best to carry out such experiments in series. Some cylinders may be pierced with a network of fine holes (fig. 5, Pl. II) and, after compression, cut across in the plane of the perforations. To get the perforations sensibly in the same plane after compression, both piercing and squeezing must be carefully done. Other cylinders, of the same dimensions but not pierced, may be compressed to the same extent as the perforated cylinders and then, after chilling, split to show cleavage. If the cylinders are squeezed too rapidly the edges will split—a contingency to be avoided because the distribution of strain then becomes irregular and eludes systematic discussion.

For experiments on scission, blocks were planed to fit the opening B as accurately as possible and the blocks were given a temperature of about 20° before straining. They were cooled and broken as in the experiments on linear compression.

Experiments with clay.—The clay used burns to a pleasing terra-cotta color, without much shrinkage. Slides of the burnt mass show that the clay contains a large amount of finely divided quartz and a small amount of black mica in minute scales. There is also a trace of organic matter in this clay, for when first heated it blackens. For use, the clay should be moistened as little as is compatible with convenient modeling and kneading.

From a well-kneaded lump of clay it is easy to cut cylinders similar to those of ceresin described above. Excellent cleavage can be produced by compressing them in a press and burning the cakes lightly in an assay muffle furnace. Indeed, to get cleavage, it is sufficient to press a pellet, say a centimeter in diameter, under a spatula and toast it over a Bunsen lamp! Yet in some respects clay is inferior to ceresin for this experiment, because cylinders, after reduction to about five-eighths of their original diameter, crack at the edges, so that the strain can not be followed systematically by the method given above. Some of these cracks are meridional and due to tension, while others occur at about 45° to the line of force and are true joints on planes of maximum tangential strain. Such a cake of clay is shown in fig. 8, Pl. II. Precisely similar cracks are produced in steel cylinders subjected to

end pressure, and it is clear from these phenomena that the moist clay behaves mechanically like a true solid, relative motion of the particles taking place at an acute angle to the line of pressure. I have tried subdividing clay cylinders by a network of pin holes in one plane, and then compressing and dissecting them as described on a previous page. Up to the point where the edges begin to rupture, the deformation is exactly the same as in the cylinders of ceresin of similar dimensions and degree of compression.

On the other hand, clay behaves better than ceresin in the scission engine, apparently because I did not succeed in casting ceresin without small bubbles of included air, while it is easy to knead the clay until air is expelled. In the scission engine there is no tendency to cubical compression provided the space B is homogeneously filled, but this proviso is essential. In experiments on ceresin one acute angle of the space B is usually found empty, and though this space is never large, it is a disturbing condition. With well-kneaded clay the space B remains full after strain, and such blocks after burning show excellent cleavage.

Clay is a very instructive material to experiment upon for two reasons: Most or much of the natural slate is of argillaceous origin; and, again, the burning of the strained clay cakes may properly be considered as a true metamorphism, which nevertheless does not obliterate the cleavage mechanically induced.

Other materials tried.—Plaster of Paris pellets compressed under a spatula at just the right moment during the "setting" process and then dried out exhibit cleavage, a fact which is interesting because of the accompanying formation of selenite crystals. I have tried plaster paste in the scission engine repeatedly, but have not been able to hit exactly the right conditions. Air bubbles get into the liquid plaster while it is being poured into the space B, and if stress is applied too soon the plaster naturally sets without any development of cleavage. Moreover, plaster seems to begin to set from the outside, so that the space B was probably never homogeneously filled with a substance fitted to display the properties of homogeneous strain.

Lead cylinders pierced with holes and afterwards filled with tin wire and then compressed show by dissection just the same strains as do ceresin blocks. Such cases are shown in figs. 7 and 9, Pl. II. Similar results have been obtained with aluminium. I had hoped that these metals, cooled to the temperature of liquid air, would become brittle enough to exhibit cleavage, but was disappointed. The lead cakes seemed as tough as sole leather and I could not produce the least indication of a crack in the aluminium by the most vigorous use of the hammer.

Strain ellipsoids in ceresin.—In fig. 2, Pl. II, is shown a series of cakes of ceresin into which spherical pellets of ceresin tinged with a

Fig. 2.

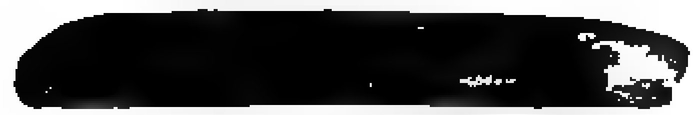


Fig. 3.

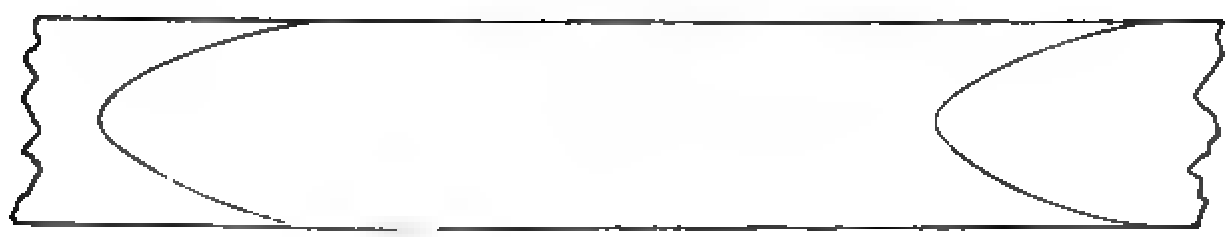


Fig. 4.

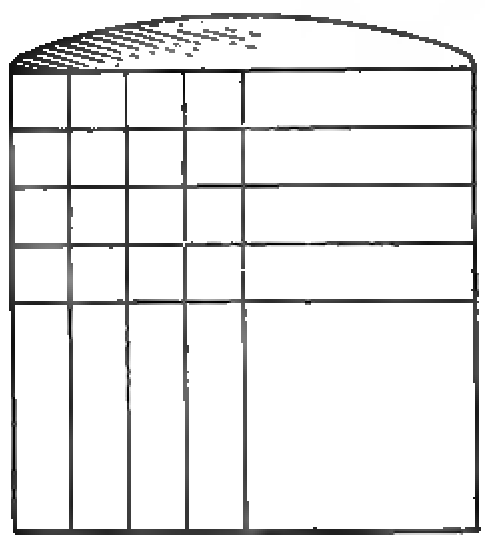


Fig. 5.

Fig. 6.

Fig. 7.

Fig. 8.

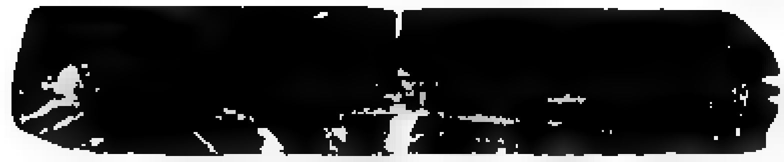


Fig. 9.

FIG. 2. STRAIN ELLIPSOIDS IN CERESIN.
FIG. 3. CLEFT STRAIN ELLIPSOID IN CERESIN.
FIG. 4. DIAGRAM OF DISTORTION IN ROLLING CLAY.
FIG. 5. DIAGRAM TO SHOW PIERCING OF CYLINDERS.
FIG. 6. CAKE OF CERESIN COMPRESSED TO TWO-THIRDS ORIGINAL HEIGHT.
FIG. 7. CAKE OF LEAD COMPRESSED TO TWO-THIRDS ORIGINAL HEIGHT.
FIG. 8. CAKE OF CLAY COMPRESSED TO TWO-THIRDS ORIGINAL HEIGHT, SHOWING PERIPHERAL RUPTURES.
FIG. 9. CAKE OF LEAD COMPRESSED TO ONE-THIRD ORIGINAL HEIGHT.

mere trace of vermilion were introduced during the process of casting. The cylinders after compression were cut radially to show the strain ellipsoids thus produced. If a composite photograph were to be taken of these and similar cases the position of the strain ellipsoid in most portions of the cross section would appear.

Many cakes containing pellets were cooled below the freezing point and split. These specimens show that the surfaces of cleavage are not parallel to the major axes of the strain ellipsoids. In some cases the cleavage developed by the hammer intersected the pellets, leaving no doubt whatever on this point (fig. 3, Pl. II). It is relatively seldom, however, that such a crack forms without splitting away a large part of the pellet and leaving some doubt as to the exact position of the major axis. Hence the observer is driven to a comparison between the dissected cakes without cracks and the split cakes. It seemed desirable, therefore, to devise a means of determining once for all the position of the strain ellipsoid in any and every part of the cake. This will now be described.

Construction of strain ellipsoids.—Fig. 5, Pl. II, is a diagram indicating the way in which cylinders were pierced with holes, forming a rectangular network covering a quarter of the cross section. A thread smeared with dry vermilion powder was drawn after the piercing needle and thus the interior of the perforations was coated with pigment.

Photographs of three cakes compressed after perforation and cut to show the network are shown on an enlarged scale in fig. 10, Pl. III. They are as nearly alike as the imperfection of the appliances used would permit. The central vertical lines in the cylinders were not absolutely central, nor were the plates between which the compression was effected accurately parallel planes. Hence, after compression the central line in each case is somewhat buckled.

From the middle one of these photographs a tracing was made, slightly modified by comparison with the other two, and then very much enlarged. In the diagram so procured ellipses were drawn by the methods explained at the end of this paper. The areas of the ellipses were next checked by a simple computation and found sensibly correct, showing that no considerable error had occurred in copying or construction. The value of the axes of the ellipses being found and the volume of the ellipsoids known, the planes of maximum tangential strain are also immediately deducible. The major axes were drawn through the ellipses and the positions of the planes of maximum tangential strain were shown by broken lines. The diagram was then reduced photographically to the same scale as the photographs from which it was derived. The result is shown in fig. 11, Pl. III.

Cleavage on the two theories.—It is now easy to draw through this quadrant of the figure representing the cross section of the cake a set of

lines which are sensibly tangent to the directions of the major axes of the ellipses, and this set of lines represents the cleavages which the cake should have according to Sharpe's theory. This result is illustrated by fig. 12, Pl. III, where, for the sake of completeness, all four quadrants are filled out. Similarly a diagram can be prepared illustrating my theory, and this is given in fig. 13, Pl. III. It will be observed that the two diagrams differ very radically and that the choice between them must be an easy one.

The system of cracks likely to occur on Sharpe's theory is made sufficiently evident by the figure just mentioned. The other theory shows an interlacing of possible fractures near the center, which is more complex and could not be entirely developed in a single cake without comminution. For this reason the most probable and impor tant fractures are given separately in fig. 14, Pl. IV.

The surfaces which at the end of the straining process are surfaces of maximum tangential strain were never at any step of the process perpendicular to the direction of greatest linear contraction. To make sure of this, I have constructed the strain ellipses for a case in which a cylinder of ceresin pierced with a network of holes was compressed to two-thirds its original length. Fig. 6, Pl. II, shows the cross section of the strained mass, and fig. 23, Pl. V, shows lines coinciding with the direction of the major axes of the strain ellipsoids for this case. Comparison of the last diagram with that previously discussed for a strain twice as great (fig. 12, Pl. III) shows their analogy, and proves the statement made in the first sentence of this paragraph.

Cleavage actually found.—It is exceedingly difficult to give satisfactory illustrations of the cleavages actually obtained by Tyndall's experiment. In the first place, the most instructive cakes are those which go to pieces under the hammer; but then the residual flakes are too delicate to be cut across radially for photographing, and were this accomplished only a single section could be figured, whereas the observer may examine them in three dimensions. Again, when the cakes are so gently hammered as merely to crack from the edges and are subsequently separated into two or more pieces, tension ruptures are produced as well as true cleavage; but these are not distinguishable in a photograph. Especially characteristic in radial section is the way in which the cleavage meets the outer edge of the cake. Seen in cross section the thinner part of the split cake at the outer edge is shaped like one horn of a crescent moon. This characteristic is shown by every cake, and yet it is not strikingly apparent in every section illustrated in figs. 15 to 22, Pl. IV, although it is well shown in several of them. The cakes break last at the axis, and here there is most danger of tension rupture in forcing the opposite portions asunder. In two or three of the specimens illustrated, however, there is evidence

Fig. 10

Fig. 11.

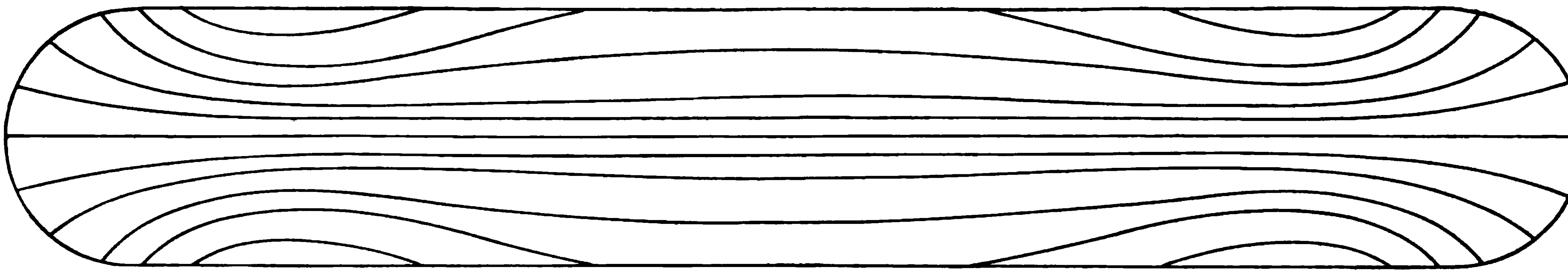


Fig. 12.

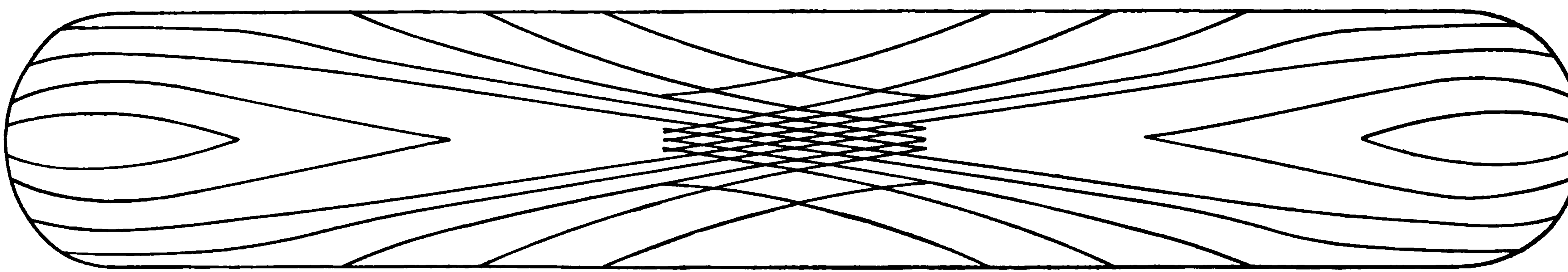


Fig. 13.

FIG. 10. THREE CAKES OF CERESIN COMPRESSED TO ONE-THIRD ORIGINAL HEIGHT, ENLARGED.
FIG. 11. DIAGRAM TO SHOW STRAIN ELLIPSOIDS IN ONE QUADRANT OF COMPRESSED CERESIN CAKE.
FIG. 12. DIAGRAM TO SHOW CLEAVAGE ON SHARPE'S THEORY.
FIG. 13. DIAGRAM TO SHOW CLEAVAGE ON BECKER'S THEORY.

of double fracture of opposite inclination at the axis (figs. 19 and 20). In figs. 18 and 21, Pl. IV, the cleavage is seen passing through the axis at an angle to the median line.

On the whole, even the photographs show a very reasonable agreement with the inference from analysis indicated as probable cleavages in fig. 14, Pl. IV. I may add that the cleavability about midway between the edge and the axis is often so perfect as to defy illustration; the flakes are frequently so thin that print can be read through them.

I must have made Tyndall's experiment a hundred times, using wax on some occasions and ceresin on others. In no case have I broken a cake which behaved as it should on Sharpe's theory, illustrated in fig. 12, Pl. III. The section of a cake most nearly in accord with that theory which I have seen is shown in fig. 22*a*, Pl. IV, and especially for that reason. Even this exceptional instance exhibits features not in agreement with that theory, while another section of the same cake (fig. 22*b*) does not at all resemble the diagram constructed for the loci of the major axes of the strain ellipsoid. The general features of the cleavage along surfaces of maximum tangential strain seem always to be recognizable when the terminations of the cylinders are plane and the compression is sufficient to produce good cleavage in the squeezed cakes, but not so excessive that the minor axes of the strain ellipsoids are reduced to almost insensible length. Evidently, in order to make any instructive comparison between the two theories, these conditions must be fulfilled.

Absence of slip cleavage.—The semitranslucency of ceresin is very advantageous for these experiments in some respects. If a cake of ceresin is examined in a strong light and at the same time partly shaded, any internal cracks can readily be detected. When cylinders are being compressed for Tyndall's experiment, between glass plates of the proper temperature, the first cracks to form seem always to be at the edge of the cake; and when the pressure is applied so gradually as to avoid this peripheral splitting I find no internal cracks unless the glass plates were too cold.

Significance of bubbles.—On the other hand, my cakes all contain numerous minute bubbles of air, carried into the mold in casting. During compression these are flattened, and are then equivalent to minute blind joints. The flattened bubbles are, of course, oriented exactly as are the strain ellipsoids. They are perfectly visible in the photographs of the dissected cakes, and comparison shows that the orientation of the bubbles is indistinguishable by the eye from that of the strain ellipsoids obtained by construction as shown in my diagram, fig. 11, Pl. III. Were the bubbles smooth internally, as they would be in a glass, it might be possible to dispense with the construction.

They are not smooth, however, and seem to be lined with minute paraffin crystals, so that their evidence, though confirmatory, is not sufficient.

I feel fully justified in asserting that there is in my experiments just described no blind jointing (Ausweichungsclivage) or slip cleavage in the directions in which cleavage actually takes place, or in directions called for by my theory of cleavage. But the bubbles tend to weaken the mass in the directions in which cleavage should occur on Sharpe's theory. Hence the weakening of cohesion, to which I attribute cleavage (along the surfaces of maximum tangential strain), must be so great as more than to counterbalance the effect of the bubbles.

The double or schistose cleavage which is called for by theory and is illustrated in fig. 13, Pl. III, is not often displayed except by the diversity in the directions of the surfaces of fracture near the axis of the cakes; but the fact that near the axis the cake may split in either of two directions shows that there are two intersecting cleavages.

Scission experiments.—The purpose of experimenting with scission was, as has been explained, to produce a simple strain which, if it could be made to lead to cleavage at all, would indicate beyond doubt whether the surfaces coincided with one of those of maximum tangential strain. In a scission one of these directions is parallel to two faces of a distorted rectangular mass, those, viz, which undergo no change of area. In this direction the same set of particles is subject to maximum tangential strain from the inception of the process to its completion, however long a time that may be. There is a second set of planes of maximum tangential strain, but as the strain increases in amplitude fresh sets of material particles continually replace one another in these latter planes, so that any one set of particles undergoes maximum tangential strain along these planes only for an infinitesimal time. Hence, either a smaller effect, or at least a different effect, will be produced on this second set of planes. If my theory is correct, cleavage is to be looked for only parallel to the planes of constant area, for reasons indicated in a note on the theory appended to this paper. With the unit shear, or when the acute angle of the distorted mass is 45°, the major axis of the strain ellipsoid makes an angle of about 32° ($\frac{1}{2}$ tan $^{-1}$2) with the undistorted planes. This strain is shown in fig. 31, Pl. VI.

Results for ceresin.—I never expected to get a perfectly smooth slaty cleavage by scission, for reasons stated in the appended note on my theory. Experiments on the scission of ceresin blocks are not very satisfactory. If the blocks have as high a temperature as I found best for Tyndall's experiment (where the strains for the most part are of much greater amplitude than my scission engine will produce), the blocks show no cleavage at all. At 20° C. and 0° C. cleavage sometimes results and is sometimes absent or insensible. When the cleav-

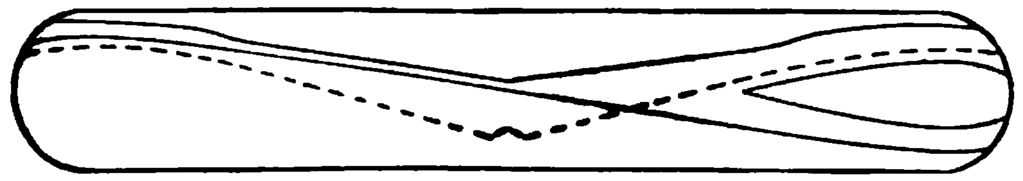


Fig. 14.

Fig. 15.

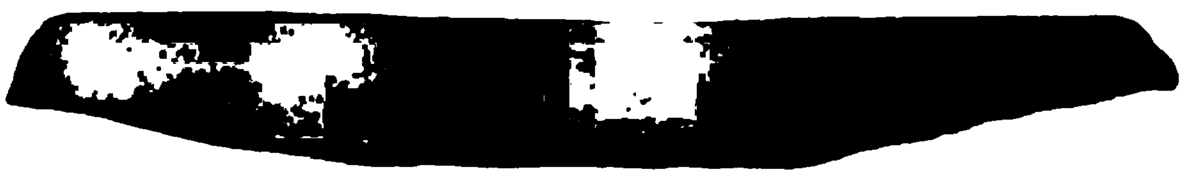


Fig. 16.

Fig. 17.

Fig. 18.

Fig. 19.

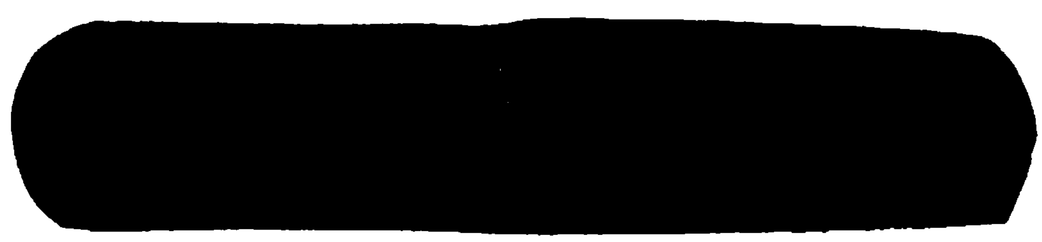


Fig. 20.

Fig. 21.

Fig. 22 *a*.

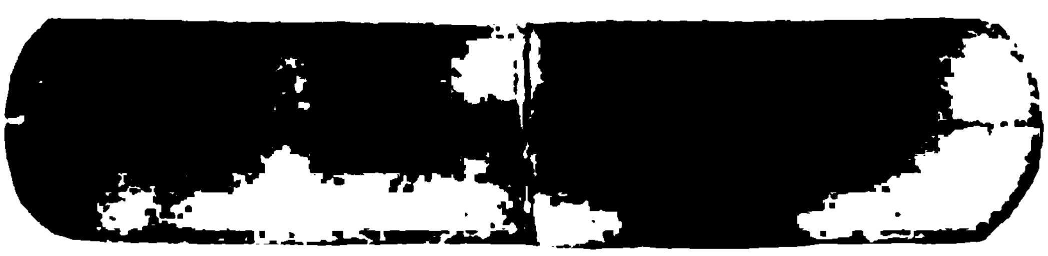


Fig. 22 *b*.

FIG. 14. PROBABLE CLEAVAGES ON BECKER'S THEORY.
FIG. 15–22. PHOTOGRAPHS OF ACTUAL CLEAVAGES.

age is a vanishing quantity or absent the mass breaks with a more or less conchoidal fracture. When there is any distinct cleavage it is parallel to the undistorted planes.

One difficulty with ceresin is that, on account of air bubbles,[a] the block does not completely and homogeneously fill the space. If it did, rupture would be impossible. In fig. 24, Pl. V, is shown an instance of rupture. The circle stamped on the block before strain is distorted to an oval which is dislocated by three tiny faults. The joints formed are exactly parallel to the undistorted plane. The truncated upper left-hand corner shows the failure to fill out the space.

In fig. 25, Pl. V, is shown a block which did not entirely fill out the space, but was not jointed like fig. 24, Pl. V. When struck on the back with a hammer it developed cracks having a tendency to parallelism with the undistorted planes. In one case, after subjecting a cake to scission, I cut off one sharp corner perpendicularly to the plane of no distortion and filled out the opposite face with a wedge, so as to reduce the block once more to a rectangle. This was again strained in the engine. After chilling it broke with some regularity. It is shown in fig. 26, Pl. V, where X is the mass which was added before the second strain.

Results for clay.—For scission clay is a far better material than ceresin, as was mentioned above, and in all the cases I have tried clay blocks subjected to unit strain and lightly burned show cleavage parallel to the planes of no distortion. A very highly instructive specimen was produced accidentally. The distorted block was dried on the water bath and then heated in an assay muffle furnace, which, however, grew hot too rapidly. The escaping water vapor burst the block into many pieces. These, fortunately, were of such sizes that it proved practicable to fit them together and restore the outlines of the block. This specimen is illustrated by a photograph (fig. 27, Pl. V). The ellipse is visible and not faulted, and the cleavage is manifestly parallel to the planes of no distortion.

Lessons drawn.—The experiments described above, which constitute a study in plasticity, appear to me to demonstrate that true cleavage (wholly free from blind joints, or Ausweichungsclivage) can be produced both in ceresin and in clay. Burning the clay does not obliterate the cleavage. The cleavage does not coincide even approximately with the direction of the major axes of the strain ellipsoids. Neither does the cleavage correspond to the position of the major axes of the strain ellipsoids at any previous stage of the strain. On the other hand, the orientation of the cleavage does correspond to the position

[a] It might be better to prepare in another way blocks of ceresin for scission. The melted mass might be very gradually cooled, with very gentle stirring, in a flat-bottomed pan, and there allowed to solidify without pouring. Then blocks could be sawn out of the mass and planed to fit the engine. Such blocks would be free from bubbles. The experiments with clay are so satisfactory that I did not try this method.

of the surfaces of maximum tangential strain. Cakes of ceresin linearly compressed exhibit and elucidate slaty cleavage near their edges. Toward their axes of symmetry they show and explain the double or multiple cleavage so characteristic of the crystalline schists. This last important phenomenon is almost unintelligible on Sharpe's theory, for if the greatest linear contraction were perpendicular to one set of cleavages in the schists, it could not also be perpendicular to the other. If it be suggested that the two (and sometimes four) cleavages were successively impressed on the schist, the answer is that observation is inconsistent with this explanation, the distribution of minerals and their mutual relations contradicting the idea. The evidence presented shows that rupture and cleavage follow the same surfaces, cleavage being due, so far as can be told, to weakened cohesion—a state of things in absolute accord with Daubrée's experiments and Heim's observation that Ausweichungsclivage and cleavage without rupture are sometimes visible in the same slide and are parallel to each other.[a] The effect of pressure in the direction of greatest linear contraction, on the other hand, is only to force molecules closer together in the line joining their centers. How this approach of molecules to one another might increase their cohesive attraction I can understand; but how it could weaken it is, to me, a mystery. So far as I know, no theory of molecular attraction has been formulated which would account for such a weakening.

The deformation of ceresin implies only a trifling expenditure of energy or a minute evolution of heat. When firm rocks are deformed, especially igneous rocks, the amount of work done or of heat evolved must be very great. That such deformation should be accompanied by the genesis of secondary minerals is in accordance with all the results of the study of metamorphism. Now, experiments of my own, not yet published, show conclusively that crystals tend to grow in the direction of least resistance, as might indeed be assumed, although they exert a linear force in any direction. Secondary minerals in a slate originating in a firm rock will thus tend to develop chiefly in the direction of cleavage. It is not improbable that the secondary development of mica on cleavage planes may further facilitate the cleavage to which it owes its existence, much as slickensides on a faulted surface facilitate further faulting. If the mica were assumed as the origin of the cleavage, it would be necessary to show how it could be generated and oriented in planes independent of the stratification without obliterating

[a] Mechanismus der Gebirgsbildung, vol. 2, 1878, pp. 56 and 59. Heim attributes cleavage to movements (Ausweichungen) of the mass perpendicularly to the direction of pressure. It is evident that he refers to *relative* movements of adjacent portions of the mass, or what I call tangential movements. These necessarily imply forces locally inclined to the direction of the relative motion, for, in general, in any solid or in any hyperviscous liquid strained at a finite rate, a tangential displacement implies a force containing a tangential component. Heim insists that rupture and cleavage, when due to one force, are parallel, a point in which I agree with him. On the other hand, master joints and false cleavage occur characteristically at angles of more than 45° to the slaty cleavage.

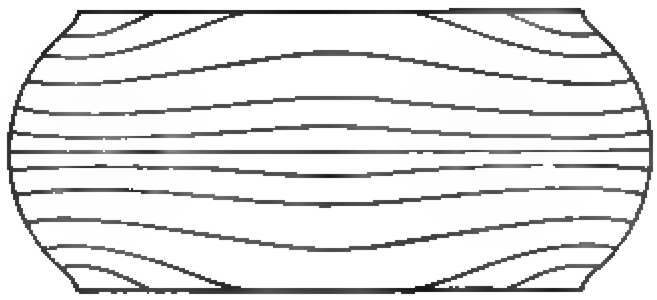


Fig. 23.

Fig. 24.

Fig. 25.

Fig. 26.

FIG. 23. LOCI OF MAJOR AXES OF ELLIPSOIDS CORRESPONDING TO FIG. 6.
FIG. 24. BLOCK OF CERESIN FAULTED BY SCISSION
FIG. 25. BLOCK OF CERESIN SHOWING CLEAVAGE DUE TO SCISSION.
FIG. 26. BLOCK OF CERESIN SHOWING CLEAVAGE DUE TO DOUBLE SCISSION
FIG. 27 BLOCK OF CLAY SHOWING CLEAVAGE DUE TO SCISSION.

the stratification, as well as why grit beds in slate show cleavage. This, it seems to me, has never been successfully done.

The experiments made would indicate that the order of linear compression in slates, supposing their volume inalterable, is about in the ratio of 1 to 3 or 4, and that it is accompanied by large slides or tangential strains; but the degree of strain needful to produce cleavage probably depends both on the nature of the material and on the rate of straining. From field observations I suspect that a compression of one-half sometimes suffices.

I infer that a slate belt is equivalent to a distributed fault or a step fault with infinitesimal steps, whose total displacement is of the same order as the thickness of the slate. The direction of this faulting (according to the results reached in my former discussion) is given by the intersection of the cleavage plane with a plane perpendicular to the grain of the slate, and is therefore ordinarily not greatly inclined to the horizon. Were the grain vertical it would indicate horizontal faulting. The major axis of the strain ellipsoid lies in the plane which is perpendicular to the grain of the slate but at a considerable angle to the cleavage.

The force to which cleavage is due lay in this same plane at an angle to the cleavage which would be zero if the strain were unalloyed scission, barely conceivable in nature, and finite for all other strains. There is no simple relation between the direction of the force producing strain and the directions of the axes of the strain ellipsoid for any case of rotational strain. In the case of slate the direction of the force lay within the acute angle between the direction of greatest linear compression (or the smallest axis of the strain ellipsoid) and the cleavage. In the case of symmetrically developed double or multiple schistosity, not infrequent in the crystalline schists, rotation was absent and the direction of force coincided with that of the smallest axis of the strain ellipsoid bisecting the obtuse angle between the cleavages. It appears probable, from the experiments, that the angle between the slaty cleavage and the local direction of the force to which it is due may vary within wide limits.

For other consequences of the theory confirmed by the experiments here described I must refer to my former memoir.[a]

[a] It is easier to test the experimental results reached in this paper, now that it is written, than to examine microscopically even a very small suite of rocks. The following method of verification is suggested: Any young student or handy janitor can prepare a set of cylinders of ceresin cast at the lowest practicable temperature, with flat ends, and of a diameter equal to the length. Keep ten or twelve such cylinders in a thermostat over night at 35° C. Compress them, three at a time, between heavy, somewhat warm glass plates in a copying press to one-third of their original length, so slowly as not to burst the edges. Put the cakes in ice and salt for an hour or more. Then cut one or more of the cakes in two on a plane which includes the axis. Examination of the minute bubbles should show whether my diagram of the distribution of strain ellipsoids adequately expresses the facts. If it does so, the figures exhibiting the alternative cleavage, according to Sharpe's theory or mine, must also be correct. Split the rest of the cakes by striking them edgewise with a hammer, and compare the cleavage with the diagrams.

MATHEMATICAL NOTES.

NOTE ON THE THEORY OF SLATY CLEAVAGE.

The theory of rupture of rock masses under pressure which I have propounded[a] is that fracture occurs along planes of maximum tangential strain, or, as it is also called, of maximum slide. Cleavage I regard as due to a weakening of cohesion, antecedent to rupture, on these same planes of maximum slide, the effects being influenced by viscosity, although the direction is independent of viscosity. For the full development of this theory the reader must be referred to the former memoir, just cited, but some essential features should be included here.

The planes of maximum tangential strain in a homogeneously strained mass are readily found. Their position relative to the major axis of the strain ellipsoid is independent of the cubical compression to which the mass may have been subjected, and of any rotation which the axes may have undergone relatively to the elements of mass. These positions are therefore dependent only on the two pure undilational shears, at right angles to each other, which determine the relative magnitude of the axes of the strain ellipsoid. These two shears may be separately considered.

The first problem is, then, to find the planes of maximum tangential strain in an irrotational shear ellipsoid. In this ellipsoid the section containing the greatest and least axes is an ellipse of the same area as the corresponding great circle of the original sphere. If the radius of the circle is taken as unity, the major axis of the ellipse may be called α (the "ratio of shear") and the minor axis will be $1/\alpha$, so that all lines in the ellipse parallel to the major axis of the ellipse exceed their original length in the ratio α, and all lines parallel to the minor axis have been reduced in length in the ratio $1/\alpha$.

In the circle draw any parallelogram, for instance one with its center at the center of figure, and from the center draw two radii parallel to the sides of the parallelogram, making angles ϑ and ϑ_1 with the major axis, and meeting the circle at points $x\ y$ and $x_1\ y_1$, as shown in fig. 28, Pl. VI. Then in the ellipse there will be a corresponding parallelogram and set of points which may be indicated by the same letters primed.

[a] Finite homogeneous strain, flow, and rupture of rocks: Bull. Geol. Soc. America, vol. 4, 1893, pp. 13-90.

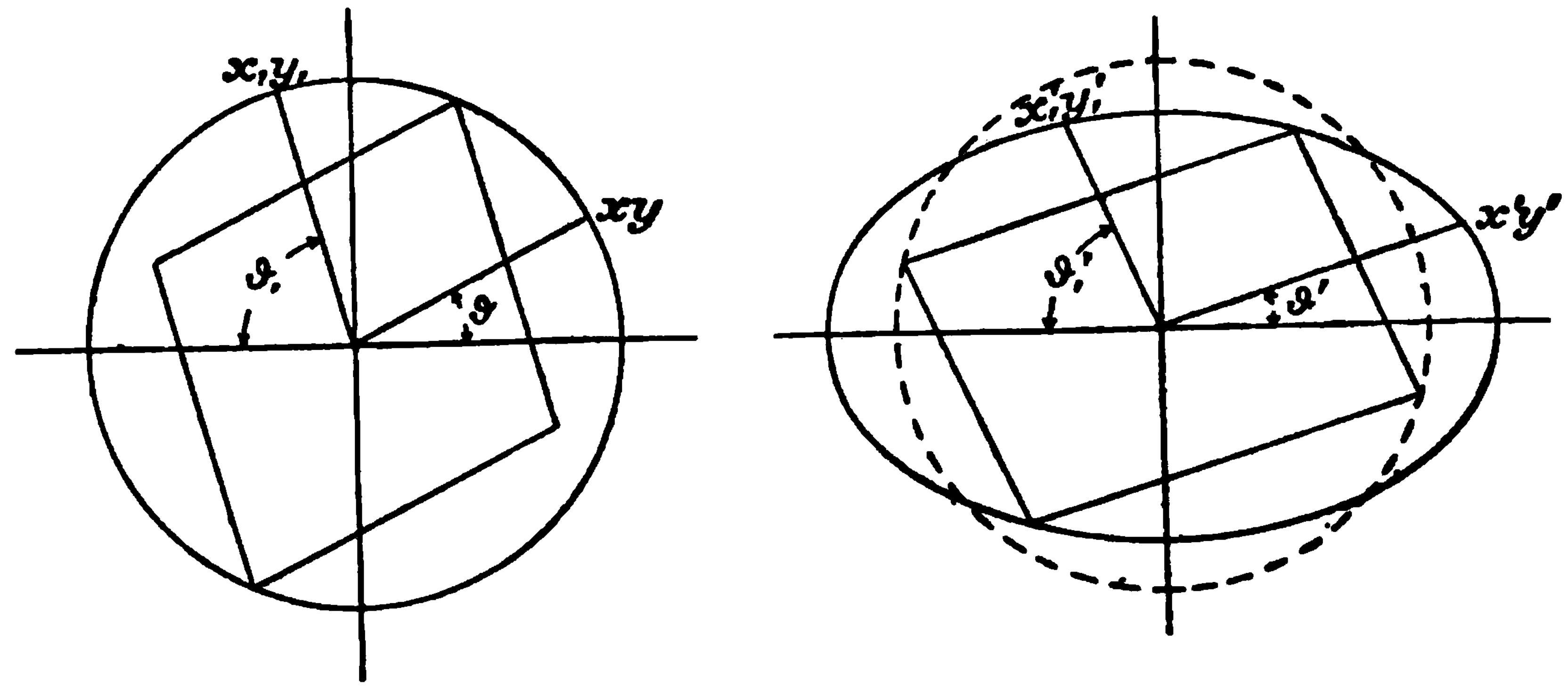


Fig. 28.

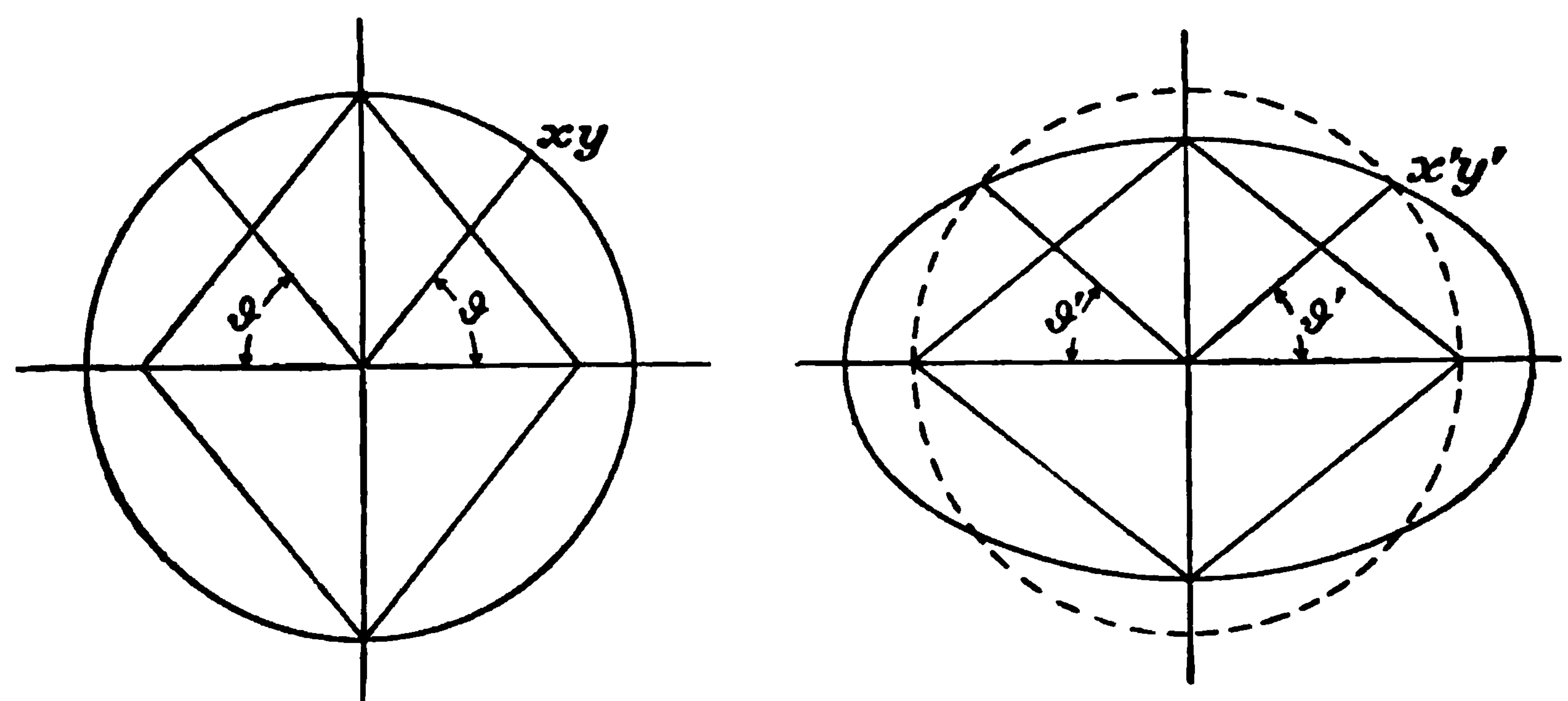


Fig. 29.

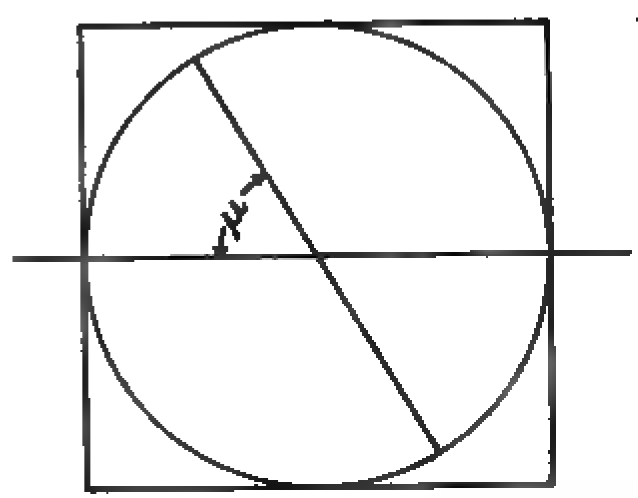
a

Fig. 29

b

c

Fig. 30.



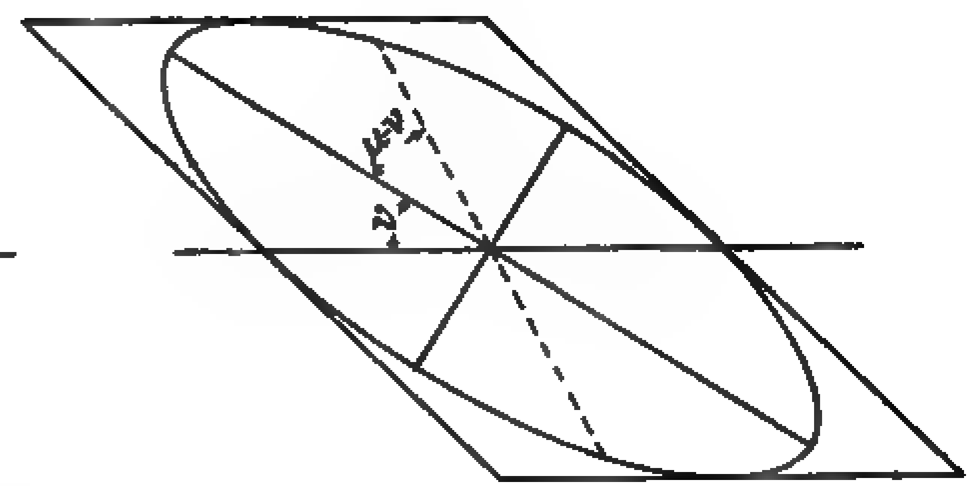


Fig. 31.

FIG. 28. DIAGRAM OF SLIDE, BUT NOT MAXIMUM SLIDE.
FIG. 29. DIAGRAM OF MAXIMUM SLIDE.
FIG. 30. PURE SHEAR COMPOUNDED OF TWO SCISSIONS.
FIG. 31. SCISSION AND ANGLE OF ROTATION $\mu-\nu$.

Now slide will change the angles of the original parallelogram, or the inclination of the radii in the circle, and the greater this change the greater the slide. If, therefore, the maximum slide is sought, the deflection of each of the two radii must be a maximum, and symmetry shows that ϑ and ϑ_1 must be equal. Hence the problem reduces to finding the radius in the circle which experiences the greatest change of direction through the strain. This is very easy, for by definition (see fig. 29, Pl. VI),

$$x' = \alpha x;\ y' = y/\alpha;$$

$$\tan\vartheta = y/x;\ \tan\vartheta' = \frac{y'}{x'} = \frac{\tan\vartheta}{\alpha^2};$$

so that

$$\tan(\vartheta - \vartheta') = \frac{\tan\vartheta\,(\alpha^2 - 1)}{\alpha^2 + \tan^2\vartheta},$$

which has its maximum value when

$$\tan\vartheta = \alpha;\ \tan\vartheta' = 1/\alpha.$$

Thus the maximum value of

$$\tan(\vartheta - \vartheta') = \frac{\alpha - \alpha^{-1}}{2}.$$

The total change of the angle of the original rhomb is measured by twice this quantity, and $\alpha - \alpha^{-1}$ is known as the "amount of shear."[a]

In polar coordinates the equation of the ellipse is

$$\frac{\cos^2\vartheta'}{\alpha^2} + \alpha^2\sin^2\vartheta' = \frac{1}{r^2},$$

and when $\alpha = \cot\vartheta'$, evidently $r = 1$, so that the directions in which slide is a maximum for a single shear are those in which the radii have preserved their original length. In other words, if the circle is superposed upon the ellipse, the intersections of the two curves are the extremities of the radii in question. Hence, also, the planes of maximum tangential strain in the shear ellipsoid are the circular sections.

This subject can also be profitably considered from another point of view, that of the stresses involved. If a rod is subjected to a finite tensile load Q, I have shown[b] that the resultant stress (force per unit area), R, the normal stress, N, and the tangential stress, T, in one component shear, may be written as follows:

$$R^2 = \frac{Q^2}{9}\left(\alpha^2\sin^2\vartheta' + \frac{\cos^2\vartheta'}{\alpha^2}\right).$$

$$N = \frac{Q}{3}\left(\alpha\sin^2\vartheta' - \frac{\cos^2\vartheta'}{\alpha}\right).$$

$$T^2 = \frac{Q^2}{9}\left(\alpha + \frac{1}{\alpha}\right)^2\sin^2\vartheta'\cos^2\vartheta'.$$

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[a] It would be much better to measure shear by the quantity $\frac{\alpha - \alpha^{-1}}{2}$, and to call this the *amplitude* of shear.

[b] The finite elastic stress-strain function: Am. Jour. Sci., 3d ser., vol. 44, 1893, pp. 337–356.

Comparing this value of R^2 with the polar equation of the ellipse, it appears that for any value of ϑ'

$$rR = \pm Q/3,$$

so that the resultant load or initial stress, or stress into final area, is the same on any section. Now, for the circular section, or $\tan \vartheta' = 1/\alpha$, $N=0$, so that the entire load is tangential, and although the tangential stress (as is well known) is greatest for $\vartheta' = 45°$, the tangential load, $\pi r\ T$, is greatest for $tan\ \vartheta' = 1/\alpha$, and then becomes $\pi T = \pi Q/3 = \pi R$. Thus, according to the theory here set forth, rupture and cleavage are determined by maximum tangential load, not by maximum tangential stress.

If a second shear is applied to the mass in a plane at right angles to the first, the effect in the plane of the first shear is only to reduce the height without altering the breadth. Consequently no further slide is produced in the plane of the first shear and no further tendency to the impairment of cohesion or to its dissolution exists. On the other hand, the angle of the planes of maximum tangential strain to the major axis of the ellipse is modified. If the final angle made by these planes with the major axis A, is ω, and if B and C are the other axes of the ellipsoid (A> C> B) it is easy to see[a] that in the plane AB

$$\tan^3 \omega = B^2/AC;$$

or if the mass is incompressible, so that $ABC=1$,

$$\tan \omega = B.$$

From the point of view of cleavage and rupture, the inner mechanism of a pure shear is important. Suppose the rhomb shown in fig. 30*a*, Pl. VI, to be divided into an infinite number of equal strips, each of length equal to a side, and that these be slid over one another as the cards of a pack can be slipped. Then the resulting figure may be a square, shown at *b*. Divide this square anew into strips at right angles to the former divisions and shift these new strips as shown in fig. 30*c*, Pl. VI. The result of the double process will be a rhomb identical with that due to pure shear, shown in the preceding diagram, fig. 29, Pl. VI.[b]

Now, not only is shear produced by this mechanism, but it seems impossible to devise any other mechanism by means of which it can be produced. The significant point is that action is almost confined to planes parallel to the sides of the rhomb; elsewhere the only relative movement which occurs is mere approach or separation of molecules on lines joining their centers. It is conceivable that the lengthen-

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[a] Bull. Geol. Soc. America, vol. 4, 1893, pp. 34 and 22.

[b] The two component strains are scissions, and it is susceptible of easy algebraic proof that if two scissions of equal amplitude are superposed in such a manner as to produce pure shear the two scission planes must be at right angles to each other. If the ratio of the resultant shear is α, the ratio of shear in each of the scissions must be $\sqrt{\alpha}$.

ing of elements parallel to the major axis should cause rupture perpendicular to this direction, or in planes parallel to the plane of the mean and minor axis. It is also true that when short cylinders are subjected to linear compression, their edges sometimes split by tension meridionally or in planes perpendicular to the plane of the two greater axes of the strain ellipsoid, and that the blocks sometimes yield along planes of maximum tangential strain. But that the approach of molecules along the smallest axis, on lines joining their centers should tend to weaken their cohesion and produce cleavage perpendicular to the smallest axis seems to me most improbable from a mechanical point of view, and I have found no experimental evidence of such an effect. Such an effect, however, is implied in Sharpe's theory of cleavage.

In a pure shear the lines of maximum tangential strain do not coincide throughout the strain with the same material particles. The first particles to undergo this strain stood originally at 45° to the line of pressure, while those which ultimately underwent maximum tangential strain originally lay at angles of less than 45° to the line of pressure— i. e., $\tan^{-1} 1/\alpha$. These lines of strain thus rotate through wedges of the strained mass. The axes of the ellipsoid, however, in any so-called pure strain coincide with the same sets of particles throughout, and maintain an invariable direction.

In rotational strains, on the other hand, the axes of the ellipsoid wander, so that successive sets of particles become axial. This rotation of the axes affects also the rotation of the lines of maximum slide. The axial rotation adds to the rotation of one set of lines of maximum slide and diminishes the rotation of the other set. Hence, in rotational strain one set of sliding planes wanders through the mass faster than the other. Consequently, also, on one side of the minor axis a given radial layer of particles is subjected to maximum tangential strain for a longer time than the corresponding layer on the other side. The angle of rotation of a strain is the angle between either axis of the strain ellipsoid and the line which passed through the same set of particles before strain began.

The extreme case of rotational strain, and the most important one, is scission (fig. 31, Pl. VI). In scission the rotation of the axes of the strain ellipsoid exactly compensates for the rotation which one set of planes of maximum strain would have in an irrotational strain of equal amount. Hence, in scission this latter set of planes does not rotate at all, or, in other words, the same set of material particles is subject to maximum tangential strain from the inception of strain to its conclusion. The other set of planes rotates through the mass just twice as quickly as it would if the strain were "pure."

Now, all real matter is viscous, and a solid displays its viscosity by yielding gradually to force up to a certain limit. A mass to which force is applied for a brief time interval resists deformation not only in virtue

of its "rigidity,"[a] but in virtue of its viscosity also. Hence, in the case of rotational strains in viscous solids, those layers of particles through which the planes of maximum tangential strain move more slowly will experience greater permanent deformation than the layers on the other side of the minor axis. These last, when the difference of rotation is considerable, will either recover elastically or rupture like a brittle body, thus giving rise to master joints and false cleavage.

Hence, according to the theory here propounded, slaty cleavage will result, in suitable material, from rotational strains, and will be found on the side of the least axis of the strain ellipsoid from which rotation takes place. In other words, it will occur at an angle to the major axis, the tangent of which is the third root of B^2/AC, but at only one of the angles so defined. It does not seem probable, from a theoretical point of view, that scission by itself will produce relatively perfect or smooth cleavage. If the cleavage due to scission alone had a certain roughness, and if the mass were further subjected to a linear compression that would reduce it to a fourth of its original thickness, this roughness would also be reduced to a fourth, or the cleavage would be four times as smooth as in simple scission. Furthermore, the conditions under which scission alone is produced must be extremely exceptional among rocks. All deformations, however, can be resolved into scissions; so that, if it were to be said that cleavage is due to strains compounded of scissions, this would merely be equivalent to asserting that cleavage is due to deformation.

NOTE ON INSCRIPTION OF AN ELLIPSE IN A PARALLELOGRAM.

This problem is easily solved algebraically if, for example, the parallelogram is derived from a square by displacements. It is thus treated in my former memoir on homogeneous strain. For such discussions as have been offered in this paper it is convenient to use a graphical method.

Let the sides of the parallelogram in fig. 32, Pl. VII, be $2a'$ and $2b'$, the value of a' being greater than that of b', and let the acute angle between the sides be ψ. Draw through the center of the figure lines parallel to the sides, then these lines will be conjugate diameters of the inscribed ellipse. By the properties of conjugate diameters these are connected with the axes a and b by the two relations,

$$(a \pm b)^2 = a'^2 + b'^2 \pm 2a'\, b' \sin \psi.$$

[a] Rigidity is resistance to change of shape when the force is so gradually applied that viscosity does not come into play. Rubber is a rigid body with a low modulus of rigidity. Rigidity in this technical sense is a property common to all solid bodies.

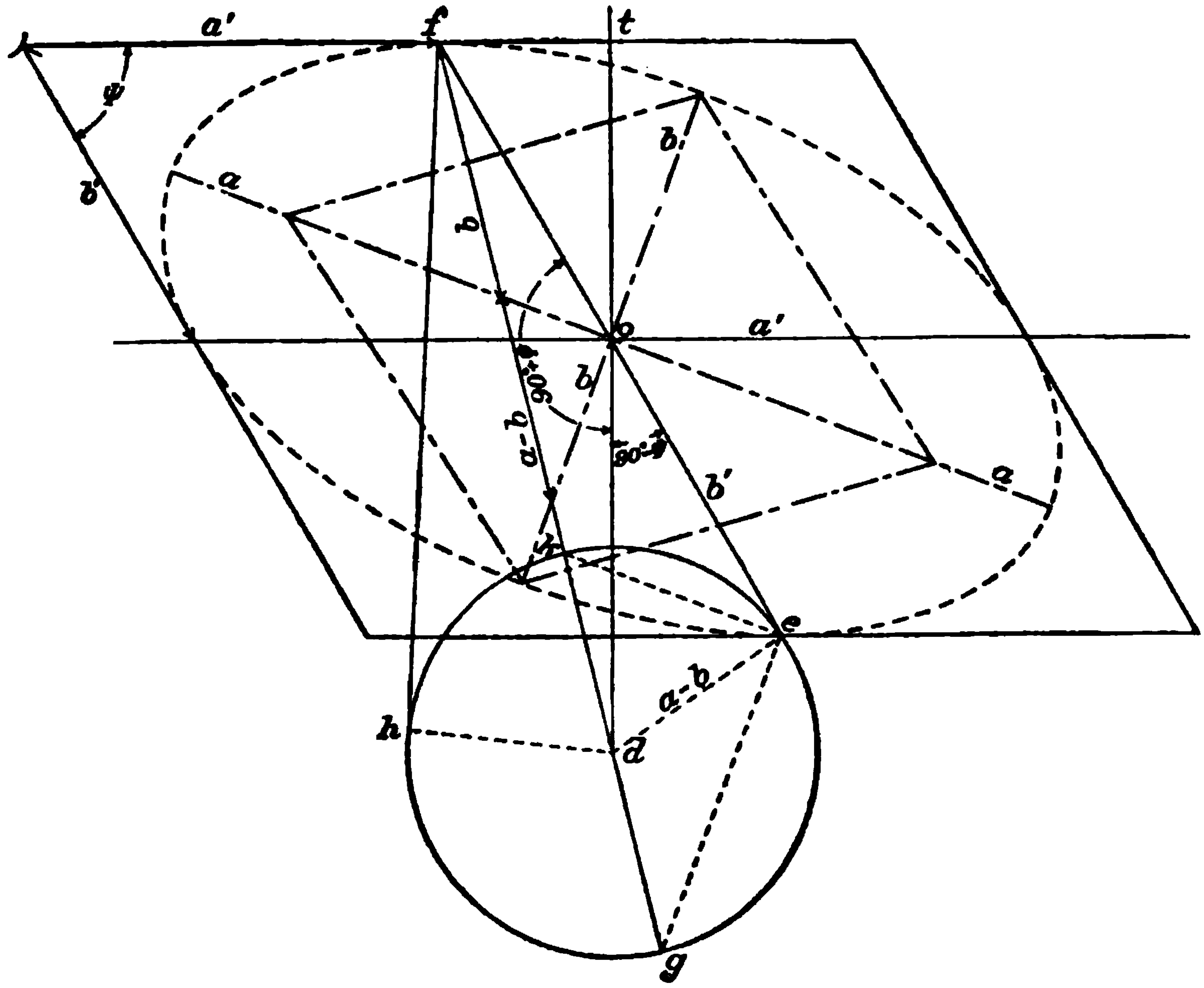

Fig. 32.

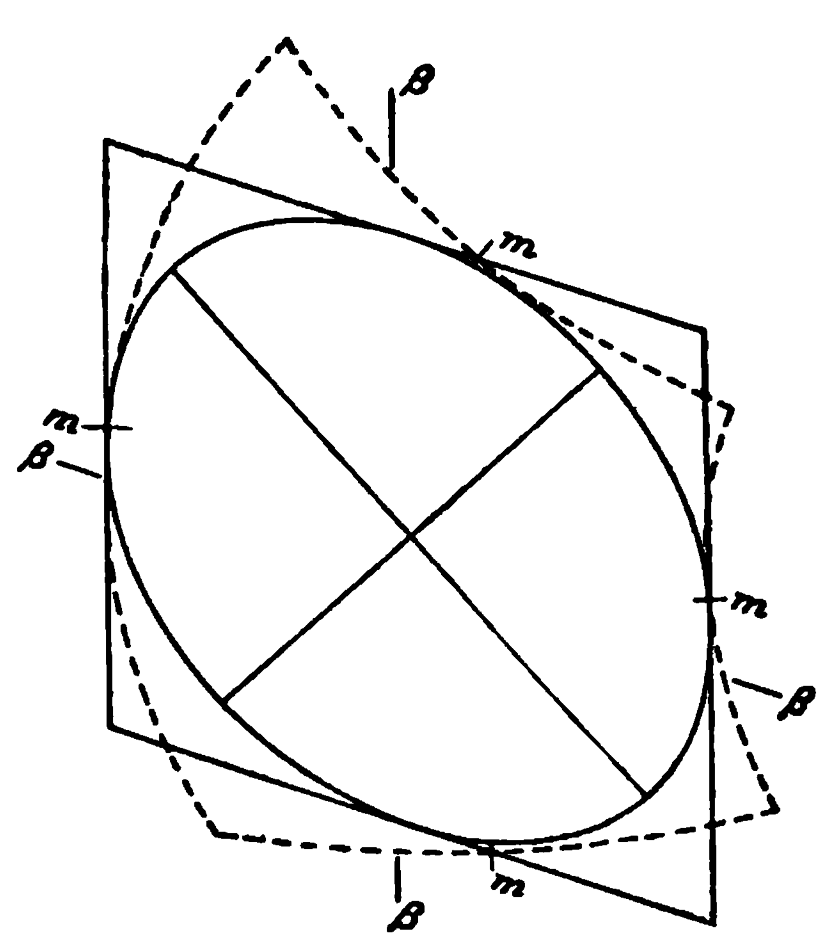

Fig. 33.

FIG. 32. INSCRIPTION OF ELLIPSE IN PARALLELOGRAM.
FIG. 33. APPROXIMATE INSCRIPTION OF ELLIPSE IN CURVILINEAR QUADRILATERAL.

From the center, o, draw a line od perpendicular to a' and of length a'. Connect the foot of b' (or the point e) with d. Then in the triangle ode the angle doe is $90°-\psi$, and therefore

$$\overline{de}^2=a'^2+b'^2-2a'b'\sin\psi=(a-b)^2.$$

Again draw from d to the top of the shorter conjugate diameter the line df. Here the angle fod is $90°+\psi$, and hence

$$\overline{df}^2=a'^2+b'^2+2a'b'\sin\psi=(a+b)^2.$$

With de as radius, describe a circle about d cutting fd at k and prolong fd to g. Then, evidently,

$$fg=2a;\ fk=2b;$$

so that the magnitude of the axes is known. To find their position, draw through o lines parallel to the chords ek and eg. The line fd will then be divided as in the ordinary construction of the ellipse, founded on the theorem that if two fixed points, on a right line, are constrained to move on rectangular axes, the curve generated by any other point on the line will be an ellipse whose greatest and least diameters lie in the given rectangular axes. The construction shows that f is a point on the ellipse. There are two positions of the axes found which are compatible with this condition, but only one which is compatible with the further condition that ft shall be tangent to the curve. Hence a is parallel to ek and b is parallel to eg.

I find that a closely analogous construction was given by Mannheim, in 1857.[a] That here presented has certain advantages.

To find the mean radius of the ellipse, draw the line fh tangent to the circle. Then

$$\overline{fh}^2=(a+b)^2-(a-b)^2=4ab;$$
$$fh=2\sqrt{ab},$$

or twice the radius required. Also the angle fdh is the acute angle between mean radii of the ellipse. If the length $\sqrt{ab}$ is set off on a, and lines are drawn from this point to the extremities of the minor axis, they will be parallel to the mean radii and correspond to the sides of the rhomb in fig. 29.

If only the position of the axes in the rhomb is wanted, it can conveniently be found as follows without determining the magnitude of the axes. Let ϑ be the angle between a and a'; then

$$\tan 2\vartheta=\frac{\sin 2\psi}{\cos 2\psi+a'^2/b'^2}.$$

To prove this equation, write the equation of the ellipse referred to its conjugates as axes in the well-known form $x'^2/a'^2+y'^2/b'^2=1$. If x and

[a] See Williamson's Diff. Calc., 9th ed., p. 374.

y are abscissa and ordinate of a point on the ellipse referred to rectangular axes, one of them containing a',

$$y' = y/\sin\psi;\; x' = x - y/\tan\psi.$$

Substitution gives an equation of the ellipse in rectangular coordinates equivalent to

$$a_{11}x^2 + 2a_{12}xy + a_{22}y^2 = 1,$$

and it is well known that

$$\tan 2\vartheta = \frac{2a_{12}}{a_{11} - a_{22}},$$

which gives the value stated above. This value may be old, but I do not recall having seen it.

When it is desirable to draw the strain ellipse characteristic of the central point of a curvilinear quadrangle representing a small portion of a strained mass, a rational method which can not be very erroneous is as follows: In fig. 33, Pl. VII, at the central points, m, of two opposite curved sides draw tangents and from their intersection a line, β, bisecting the angle between the tangents. Proceeding in the same way with the other two curvilinear sides, find a second bisectrix. Next draw through the middle points, m, of the curvilinear sides lines parallel to the bisectrices. These parallels form a parallelogram in which, as shown above, it is easy to inscribe an ellipse, which, however, may not make an exact contact with the curved sides, though it usually approaches closely to contact.

To examine the legitimacy of this construction, suppose that not merely the sides were given but a large number of intermediate curves. Then at the center there would be a small parallelogram whose sides would have directions intermediate between the tangents at the points m. Evidently the simplest hypothesis is that the directions of these sides would each be the mean of those of the two opposite tangents, and this assumption is made in the construction. Though the spacing of the intermediate curves would in general vary, it is perfectly legitimate to assume that for small distances the spacing would vary linearly, so that in the central parallelogram points corresponding to m would lie at distances apart which are simply proportional to those of these points on the curvilinear quadrangle. No further assumption is made in the construction, and I can see no doubt that it is sufficiently accurate for any such purpose as that to which it has been applied in the foregoing paper.

NOTE ON COMPUTATION OF TAN ω.

Let a, b, c be the axes of the strain ellipsoid, c being vertical to the plane of the diagram, and let $r^3 = abc$. If x is the original distance of

a point from the axis of the cylinder and x' the final distance of the same point from the axis of the compressed cake,

$$\frac{c}{r}=\frac{2\,\pi\,x'}{2\,\pi\,x}=\frac{x'}{x},$$

$$\frac{rx'}{x}=\frac{r^2}{ab}=c,$$

$$\pi\,ab=\pi\,r^2\,\frac{x}{x'},$$

the area of the ellipse. In preparing fig. 11, Pl. III, I found that the ellipses obtained by construction agreed very fairly with the last formula. The differences seemed due to slight inaccuracy in reproducing the network of curved lines in the dissected cakes, fig. 10, Pl. III.

The angle ω is given by

$$\tan^2\omega=\frac{b^2}{r^2}=\frac{x}{x'}\,\frac{b}{a},$$

or if A and B are the axes found by construction, and if it is assumed that $B/A=b/a$,

$$\tan\omega=\sqrt{\frac{x}{x'}\,\frac{B}{A}}=\frac{b}{r},$$

and

$$\sqrt{\frac{x}{x'}\,\frac{A}{B}}=\frac{a}{r}.$$

In fig. 11, Pl. III, the ellipses are plotted from the computed axes, the ellipticity and orientation being derived from the construction. Only a very minute examination would distinguish this from a diagram depending solely on construction.

NOTE ON VOLUME CHANGES IN THE FORMATION OF SLATE.

In some theories of slaty cleavage, cubical compressibility of the mass is invoked to explain certain phenomena; but it seems very doubtful to me whether this can play any notable part in the process of slate making. In plastic deformation a mass must first be strained to the elastic limit, at which there is a cubical compression corresponding to the intensity of the force (or to the stress) needed to produce this strain. When the stress is increased above this limit plastic deformation sets in and is attended by no further change of volume. Thus

the change of volume is a function of the stress at the elastic limit, and the cubical compression is one-third of this stress divided by the modulus of compressibility.

Now, slates are in part derived from structureless shales which, at any considerable distance beneath the surface, are moist. Their compressibility must be intermediate between that of water and that of their mineral components. Other slates, again, are produced from firm rocks like granite. The moduluses of compression of shale and granite are not known; that of water is 21×10^6 grams per square centimeter; that of quartz, 387×10^6 (Voigt), and that of glass from 347×10^6 to 437×10^6 (Everett). Again, the breaking strain of concrete under compressive loads is from 80,000 grams per square centimeter upward, and that of granite is 1,006,000 (v. Bach). Of course the elastic limit is lower than the breaking strain. Now, if shale is as strong as an inferior concrete and as compressible as water, the cubical compression at the elastic limit will be

$$\frac{.08\times10^6}{3\times21\times10^6}=.0013;$$

and if granite is as compressible as quartz, the cubical compression when it begins to flow will be

$$\frac{1.006\times10^6}{3\times387\times10^6}=.00087.$$

In each case the cubical compression (which is three times the linear compression) turns out nearly one-tenth of 1 per cent, a quantity the evidences of which it would be very difficult to trace in the field. It seems to me that the change in volume of shales and granites must be of this order, and that, for most purposes, they may be regarded as incompressible.

Doubtless the metamorphism and hydration of slate is attended by changes in density; but densities of 2.60 to 2.80 appear to include some clays, all the clay slates and phyllites of which I have a record, and the more typical granites. These densities thus afford no evidence that considerable increase in density attends the development of cleavage.

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Bulletin No. 242 Series B, Descriptive Geology, 47

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

GEOLOGY OF THE HUDSON VALLEY BETWEEN THE HOOSIC AND THE KINDERHOOK

BY

T. NELSON DALE

WASHINGTON
GOVERNMENT PRINTING OFFICE
1904

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DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., May 11, 1904.

SIR: I have the honor to transmit herewith the manuscript of a report on the geology of the Hudson Valley between the Hoosic and the Kinderhook, by T. Nelson Dale, and to recommend its publication as a bulletin.

Very respectfully,

C. W. HAYES,
Geologist in Charge of Geology.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

GEOLOGY OF THE HUDSON VALLEY BETWEEN THE HOOSIC AND THE KINDERHOOK.

By T. NELSON DALE.

INTRODUCTION.

This paper treats of a strip of the Hudson Valley between the Hudson River on the west and the Rensselaer Plateau and the Taconic Range on the east. It is roughly bounded on the north by the Hoosic and on the south by the Kinderhook, and has an area of about 315 square miles, situated mostly in Rensselaer County but partly in Columbia County, N. Y.; it includes a portion of the area of the Cohoes, Troy, and Kinderhook sheets of the topographic atlas of the United States Geological Survey.

This area presents several geological problems which have long been in process of solution. These are: The delimitation and age of the several formations, the order of their local deposition, and their present structural relations. These problems would be easily solved but for the rarity of fossil localities and the obscure character of many of the fossils, the petrographic similarity of beds belonging to several formations, the minor overturned folding which marks almost the entire belt, the reverse faulting in places, and the general prevalence of glacial deposits.

The publication of this paper carries out a design originated by Prof. Raphael Pumpelly, while in charge of the Archean division of the United States Geological Survey, to carefully study a belt, from 20 to 40 miles wide from north to south, extending from the highly metamorphic zone of the Green Mountain range in Massachusetts to the zone of unaltered sediments at the Hudson River. Monograph XXIII of the United States Geological Survey, on the Green Mountains in Massachusetts (1894), and the writer's paper on the Rensselaer Plateau in New York (1893), marked the execution of the more important part of this plan, and the present paper completes it.

This paper does not claim to be exhaustive, but is intended to facilitate more minute explorations by others, as well as the extension of

the work southward and northward. It is offered as a contribution chiefly to the stratigraphy of the region, paleontological investigations having been made entirely subsidiary to that and having been confined to the reference of fossils to paleontologists for determination.

The paper presents mainly the results of three months' field work done by the writer, assisted by Mr. Louis M. Prindle, in 1893, and also of a month's work, without his assistance, during 1890, 1891, 1894, and 1895, of another month's work in 1898 and 1899, and of about three weeks' work in 1901, in all equivalent to eight and three-fourths months' field work by one person. On the map (Pl. I) are shown several important fossil localities, some hitherto unpublished, discovered by Mr. Charles D. Walcott prior to 1890, some fossil localities discovered by Ford in Troy, and several localities either discovered or located in Troy and Nassau by Mr. August F. Foerste during a three weeks' reconnaissance made in 1892 and in a few days of 1890. Mr. Foerste submitted a report of his detailed work about Troy to Professor Pumpelly, from which a few quotations and figs. 13 and 14, which embody his general results, have been taken. Figs. 4, 5, and 6 are from Mr. Prindle's note book. Paleontological determinations have been credited in their places. Mr. Rudolf Ruedemann's published graptolite localities on the Deep Kill and at Schaghticoke are specially designated on the map.

The extension of geological field work by this Survey in recent years through the Cambro-Ordovician belt, along the west side of the Taconic Range, in Washington County, N. Y., and Rutland County, Vt., has thrown much light on the relations of these formations in the Hudson Valley, and will facilitate the interpretation of the phenomena to be described.

LITERATURE.

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(See also other paleontological articles by the same author in vols. 11, 1876, and 19, 1880, of same journal.)

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TOPOGRAPHY.

The most salient topographic feature in this tract is the line of hills bordering the horizon on the east, and ranging in height from 1,200 to 1,400, rarely to 1,600, feet above sea level. This is the western edge of a plateau only a third of whose area appears on the map. Along the central part of the eastern edge of the tract here mapped this plateau is 3 miles wide, but in Grafton, at the north, and in Nassau, at the south, the plateau front recedes farther eastward. South of this plateau a somewhat irregular mass of hills, belonging to the Taconic Range and ranging from 800 to 1,150 feet above sea level, advances westward as far as Chatham. Between the point where the

northern edge of the plateau turns eastward and the Washington County line there are no highlands.

The lowland is marked by numerous more or less oval hillocks, usually from 100 to 200 feet high, and mostly of glacial origin. Two conspicuous isolated hill masses, Mount Rafinesque in Brunswick (1,107 feet), with the adjacent Rice (or Bald) Mountain (925 feet) in Lansingburg, and Curtis Mountain (Dusenbery Ridge) in Nassau (1,180 feet), rise from 500 to 600 feet above the lowland. The lowland drops gradually from the 600- and 700-foot levels at the east to the 250-foot level at the west in a distance of 7 to 11 miles, and within another mile descends to tide water. The drainage is all to the Hudson. The principal streams, beginning at the north, are the Hoosic, the Poesten Kill, the Wynant Kill, the Moordener Kill, and the Kinderhook. Numerous smaller streams enter the Hudson directly, having cut deep ravines in the terrace-capped shales which form its eastern bank. The Hoosic, near Schaghticoke, has cut a canyon nearly 200 feet deep through similar materials. The Poesten Kill, which drains a large part of the plateau, flows through a deep incision in its western edge, and has cut a small gorge 2½ miles east of the Hudson and another at Troy. Owing to the glacial deposits and river terraces outcrops occur chiefly along the watercourses.

For the general physiography of the region the reader is referred to the writer's forthcoming "Taconic Physiography" (No. 21, p. 11).

AREAL GEOLOGY.

The principal geological traits of the strip are shown on the map (Pl. I). There is a central longitudinal Cambrian belt, consisting mainly of shale, extending from the Washington County line to Chatham Center and beyond, which is from 1¾ to 11 miles wide. This Cambrian belt includes, however, two outliers of upper Ordovician age, one covering about three-fourths of a square mile in North Greenbush, the other about 9 square miles, including Mount Rafinesque and Rice Mountain, and situated partly in Brunswick, Pittstown, Lansingburg, and Schaghticoke. This Cambrian belt is bordered on the west by the upper Ordovician shale and grit through which the Hudson flows, the boundary between the two formations being probably a fault. At the north the Cambrian belt narrows, and is bordered on both sides by Ordovician shale and grit. Ordovician areas likewise recur at the south, alternating with Cambrian strips, and also in places along the foot of the plateau. South of the plateau Ordovician schist, the metamorphic equivalent of the shale and grit, constitutes the Taconic Range and merges into these at the west. There are also a number of very small areas of Beekmantown shale (lowest Ordovician) overlying the Cambrian. Finally, the Rensselaer grit, with its interbedded slate

and shale, representing the basal part of the Silurian, constitutes the plateau, besides an outlying lenticular area of 4½ square miles in Nassau and Chatham, another of half a square mile near North Nassau, and a much smaller area resting on the Ordovician schist near Spencertown in Austerlitz, 12 miles south of the plateau.

Each of these formations will now be described in detail.

LOWER CAMBRIAN.

FOSSIL LOCALITIES.

The map shows 30 localities of Cambrian fossils, all Lower Cambrian (*Olenellus* fauna), according to determinations by Ford, Walcott, or Foerste. The fossils usually occur in small limestone beds in the shale. In places the limestone is made up so exclusively of *Olenellus* fragments as to deserve the name Trilobite limestone. In some places pteropods are frequent; in others, brachiopods.

Besides these there are 5 localities where the calcareous alga or nullipore, *Oldhamia* (*Murchisonites*) *occidens* Walc., has been found. These are designated by a separate symbol on the map. (See paper No. 10, p. 11. Mr. Walcott's figure is here reproduced fig. 1.) The description of the localities, sent to him by the writer for inclusion in that paper and therein published, is here repeated:

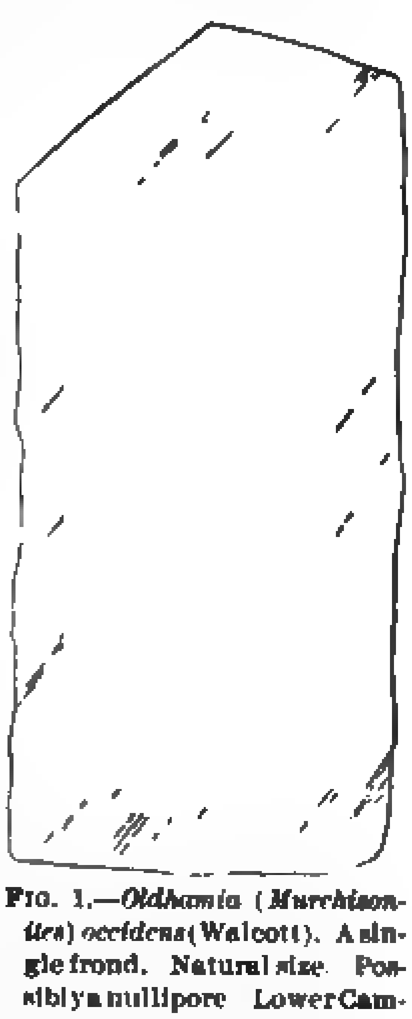

FIG. 1.—*Oldhamia* (*Murchisonites*) *occidens* (Walcott). A single frond. Natural size. Possibly a nullipore. Lower Cambrian. From the gorge of the Poesten Kill, 2½ miles east of Troy. Copied from Proc. Nat. Mus., vol. 17, 1894, p. 314, fig. 1.

> The *Oldhamia* was first found in reddish shales associated with greenish shales and beds of quartzite, ranging from 1 to nearly 22 inches in thickness, at a sawmill dam midway between Burden Lake and Nassau Pond, in the township of Nassau; again in similar rocks about 2 miles farther up the same stream and 1½ miles south-southeast from the south end of Burden Lake. It occurs also on the Moordener Kill, about 1¼ miles northeast of Schodack depot, in the township of Schodack, and in great abundance in the gorge of the Poesten Kill, 1¾ miles east of Troy, near the Eagle Mills [Millville] road, along the right bank of the river, which there flows south. The *Oldhamia* is here associated with various trails, and both cover large surfaces of the rock.

Still another *Oldhamia* locality is about a mile east of Nassau village, between two road corners, on the north side of the road. The fossil will probably also be found near the South Schodack railroad crossing and at many other points. The locality near Troy is the most accessible and the most likely to reward collectors.

Mr. Walcott regarded this *Oldhamia* as closely related to the *Oldhamia antiqua* of the Cambrian of Ireland, but "the determination of

the geologic horizon" as "somewhat uncertain." His assignment of the reddish shale to "the post-Lower Cambrian and pre-Trenton" was based mainly upon the writer's interpretation of the stratigraphy at that time, when the reddish shale seemed to him to overlie the Lower Cambrian fossiliferous limestone. The determination of the precise position of this reddish and greenish shale with beds of quartzite of various thickness with reference to the Lower Cambrian limestone is attended with no little difficulty. The reddish color is not a safe guide in this region, for such shale is sometimes associated with black graptolite shale and is then of Trenton-Hudson age. It is also interbedded with the Rensselaer grit, and then belongs to the Oneida and Medina. But in places it also occurs below the Lower Cambrian fossiliferous limestone. The stratigraphic reasons for finally assigning the *Oldhamia* shale to this last position will be given under "Stratigraphy."

FIG. 2.—Fossil casts of organic impressions in quartzite from the Lower Cambrian shale in brook bed a mile north of Poestenkill village Redrawn from a photograph taken by Dale and Foerste.

The same series of alternating red and green shale and small quartzite beds is also marked by annelid trails and casts of bifurcating impressions which have as yet no chronological or paleontological importance. These casts are, however, here quite characteristic of the series, which also carries the *Oldhamia*. Fig. 2 will serve to convey an idea of their general appearance and dimensions. As the forms stand out in relief on the quartzite surfaces the impressions themselves must have been made on the clay surfaces and then filled with sand, which has become quartzite or grit. The more important outcrops of this typical shale are indicated on the map.

PETROGRAPHY.

Certain rocks of the Lower Cambrian have such marked characteristics as to deserve special notice. A metamorphic olive grit, usually weathering a light brick red, crops out at a few points, and is also typical of this formation in Washington County. (See p. 179 of the paper No. 13, p. 11, for microscopical description.) It occurs one-half

mile east of Lake Ida, in Troy, and also north of its eastern end; one-half mile southwest of Wynantskill; at the milldam in Raymertown; at Brunswick Center; in Lansingburg, at Oakwood Cemetery, on the north side of the outlet of the pond, where it contains organic impressions and is in contact with the Ordovician shale; and at a point a mile south of Grant Hollow.

Still more characteristic of the Cambrian, and of much more frequent occurrence, is a calcareous sandstone and an associated limestone breccia. (See pp. 183, 184 of No. 13, p. 11, for a description of this sandstone as it occurs in Washington County.) This rock usually consists of roundish quartz grains held together by a cement of crystalline and granular calcite or of dolomite. On the weathered surface these grains stand out in relief and are slightly opalescent. They are even noticeable in the loose stones of the rye fields, and may be taken as an almost infallible indication of Cambrian age. Associated with these quartz grains is an occasional grain of plagioclase. Pebbles of carbonaceous-siliceous shale or of chloritic shale are quite characteristic of this rock. There are also oölitic calcareous spherules from 0.12 to 0.75 mm. in diameter, which are sometimes ferruginous, suggestive of rhizopods, and grains of limestone consisting of similar spherules. A microscopical drawing of the rock is shown in Pl. II, *A* (p. 20).

FIG. 3.—Sketch of a specimen of calcareous sandstone with small brecciated limestone or dolomite beds, typical of the Lower Cambrian of Rensselaer County. About one-third natural size. Locality, south of Lake Aries, in North Greenbush. From Sixteenth Ann. Rept., pt. 1, p. 569.

This sandstone very often includes beds of bluish fossiliferous limestone from one-half to 1 inch thick, which are generally brecciated, probably because of their greater rigidity under lateral compression than the intervening sandstone. (See fig. 3, which is taken from p. 569, fig. 99, of paper No. 12, p. 11.) The abutments of the grade crossing a mile south-southwest of the Lansingburg reservoir are built of this material and exhibit well its general character.

This sandstone is frequently associated with (either passing horizontally into or underlain at no great interval by) a quartzite in which the cement is either very slightly calcareous or sericitic. Both sandstone and quartzite are apt to be traversed by a network of veins and veinlets of quartz, which, owing to the rapid weathering of the $CaCO_3$ of the cement, project on its surface. This sandstone crops out in

Oakwood Cemetery in Lansingburg, and continues north northeast for a mile to a hillock, known locally as "Diamond Rock," on account of its abundance of quartz crystals; these occur in association with such veins.

The more important outcrops of the olive grit and of the calcareous sandstone and breccia are shown on the map, Pl. I. Outcrops of the latter at which fossils were found are, however, designated simply as fossil localities.

A limestone conglomerate deserves notice. Two miles south of Schodack Landing (Coxsackie quadrangle), or 7 miles west-southwest from North Chatham, the Cambrian shale and limestone form a cliff about 70 feet high (fig. 17, p. 28). Near the top is a bed about 10 feet thick, the lower part of which is a brecciated limestone, but the upper resembles a conglomerate; and it looks as if the brecciated limestone had for a while been exposed to wave action. The pebbles are limestone carrying Lower Cambrian fossils, but the cement is shaly. Some of the pebbles have pitted surfaces. This bed is capped by a few inches of coarse-grained limestone also carrying Lower Cambrian fossils. At Ashley Hill, a mile northeast of Riders Mills, in Chatham, the brecciated Cambrian limestone seems also to pass into a conglomerate, and the pebble-like nodules are likewise pitted from the impression of the quartz grains of the matrix. This pitting will be found explained and illustrated in pp. 312, 313, and fig. 24 of paper No. 9, p. 11. Foerste traced similar pebbles in the Cambrian shale at Troy to small limestone beds which had undergone a process of brecciation, slip cleavage, and partial solution. (See p. 569, fig. 100, of paper No. 12, p. 11.) Such "pebbles" might also be accounted for by a concretionary process taking place in sediments which were partly calcareous and partly argillaceous; or, finally, by a slight crustal movement exposing the limestone to wave action during a brief period and then submerging it again. The applicability of the first two theories should be carefully tested before resorting to an explanation involving geographical changes. It is, however, quite possible that such changes did occur here in Lower Cambrian time, and that in some localities there are true conglomerates[a], in others autoclastic ones.

A greenish shale, occasionally slightly reddish or blackish, covers a number of square miles of the Cambrian area. In places it underlies and is interbedded with the fossiliferous limestone. Under the microscope it is a very fine-grained aggregate of muscovite and chlorite scales, angular quartz grains, rarely plagioclase grains, with brownish dots which are probably limonite. The direction of the bedding is shown by bands of quartz grains, but the bedding foliation is crossed by an incipient slip cleavage, so that the muscovite scales

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[a] Walcott, Charles D., Paleozoic intraformational conglomerates: Bull. Geol. Soc. America, vol. 5, pp. 191-198, Pls. V-VII, 1894.

appear as if arranged in two directions, at a large angle to each other. Pl. II, *B*, shows a microscopical drawing of this shale. The ledge from which the specimen came has bedding planes striking N. 5° E. and dipping 35° W., crossed by a cleavage foliation striking N. 7° W and dipping 70° E., besides vertical joints striking N. 70° E. In consequence of these three systems of partings the rock weathers into stick-like fragments, and this mode of weathering is very common in this shale. The economic importance of this will be shown under "Economic geology." The microscopical composition and structure of this shale indicate that it would probably not have required a vastly increased amount of compression to transform it into schist.

This shale is very frequently interbedded with quartzose beds, weathering rusty-brown, from one-half inch to 2 inches thick. These little beds, when examined microscopically, prove to range from an almost pure quartzite to a dolomitic quartz grit. With the quartz grains, which are generally angular, are always a few of plagioclase and of zircon, and sometimes scales of muscovite and of chlorite and grains of tourmaline. The cement varies in quantity and in material, being sometimes purely siliceous, or partly siliceous and partly calcareous or sericitic, and sometimes entirely dolomitic. There are also black particles, probably graphite, and there is limonite staining from the decomposition of pyrite or carbonate. A typical section of the more gritty beds is shown in Pl. II, *C*.

There remain to be described certain greenish coarse and fine quartzite beds interbedded with the red and green shale bearing *Oldhamia occidens*. These differ little from those just described except in the occasional abundance of chlorite or chlorite-schist areas or fragments. Belonging to the same series are beds of massive quartzite, from 8 to 50 feet thick, of similar character, but including here and there small beds of quartz conglomerate, in which the pebbles measure up to one-fourth and even one-half inch in diameter, and occasionally a pebble of dark-greenish slate.

The reddish shale associated with all these quartzite beds varies much in the amount of its hematite and, therefore, in the intensity of its color. In the gorge of the Poesten Kill, a little east of Troy, and also in other places, the color is purplish. In the hill mass west of Burden Lake the red is deep. The green shales owe their color to chlorite, the purplish ones probably to chlorite and hematite, and the blackish ones, naturally, to carbon.

STRATIGRAPHY.

The paleontological evidence as to the age of these beds having been given, and their petrographical features shown, they will now be examined stratigraphically. At the outset, however, it must be stated that

it is impossible to determine their total thickness, because they consist so largely of closely folded and easily weathering shale and because there are so few deep cuts across them. When a bed of quartzite disappears beneath the shale, there are no means of identifying it and fixing its position in a series which includes several such beds. A number of detail sections of the Cambrian beds follow, which will afterwards be generalized in tabular form. Their relations to the Cambrian series of Washington County, N. Y., and of the Green Mountain range, in Massachusetts and Vermont, are shown in the table on page 43 and are discussed on page 50.

About a half mile northwest of East Nassau the Kinderhook turns at a right angle to flow south between two steep hills. The eastern hill consists of Rensselaer grit, but the western one of thick beds of quartzite and thin-bedded red and greenish shale, which, for reasons to be given, are all regarded as being Lower Cambrian. Fig. 4 represents a diagrammatic cross section of this hill. It shows two thick beds of

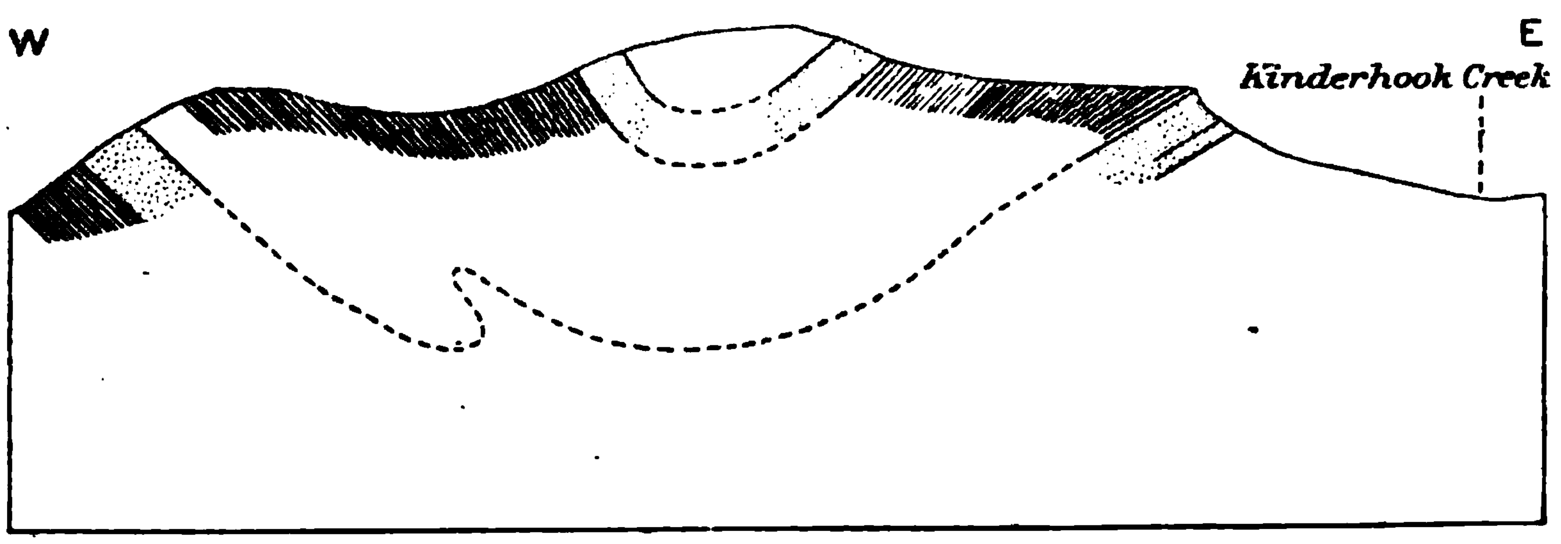

FIG. 4.—Diagram section of first ridge west of Kinderhook Creek and Snake Hill, in Nassau. Dotted beds, quartzite; lined beds, shale. Height, about 200 feet. Quartzite, about 80 feet thick.

quartzite and two masses of shale. The lowest of these shale beds is red, and the upper contains small beds of quartzite. This same series recurs 2 miles north-northeast along the strike, making up the ridge on the east side of Tackawasick Pond, which continues 2 miles north to Hoag Corners. The structure of this ridge is complex. At the extreme north it consists of a simple syncline of massive quartzite underlain by red shale, as shown in fig. 5 (p. 21). About a half mile south a small anticline of the same rocks appears east of this syncline, and within another half mile another syncline is added east of that anticline. Combining the observations made at all points the structure of the whole ridge appears to be approximately as shown in fig. 6 (p. 21), and thus, like that shown in fig. 4, consists of two thick quartzite beds separated by red shale, and the lower quartzite also underlain by red shale. There is considerable variation in the thickness of the quartzite; the bed sometimes divides into smaller ones, and these unite again farther on. The folds here have a marked northerly pitch and have been greatly eroded.

PLATE II.

PLATE II.

MICROSCOPICAL SECTIONS OF TYPICAL ROCKS.

A. Microscopical drawing of two thin sections of calcareous sandstone typical of the Lower Cambrian of Rensselaer County, showing roundish quartz grains (unshaded), grains of concretionary limestone containing quartz grains, grains of granular limestone or dolomite (finely dotted), large ferruginous concretions, and a small grain of plagioclase, all in a matrix of crystalline calcite with some large plates of calcite.

B. Microscopical drawing of thin section of greenish shale typical of the Lower Cambrian of Rensselaer County, from near Nassau village. The section crosses three minute beds, two of which are made up largely of quartz grains (unshaded particles). Direction of bedding shown by arrow. The position of some of the muscovite and chlorite scales (black particles) shows an incipient cleavage. Two grains of plagioclase (banded).

C. Microscopical drawing of a thin section of a small gritty bed typical of the Lower Cambrian shale of Rensselaer County, from one-fourth mile north of Lake Ida, in Troy, showing angular quartz grains (unshaded), three plagioclase grains, and two zircon grains, in a matrix mainly of sericite.

D. Microscopical drawing of a thin section of grit typical of the Hudson formation of Rensselaer County, from 1½ miles south of Grandview Hill, in Greenbush, showing angular quartz grains (unshaded), grains of plagioclase and orthoclase, two grains of zircon (lower left corner), one large grain of quartzite, presumably of Cambrian origin, and some carbonaceous matter (black), all in a matrix of fine argillaceous material with considerable calcite (finely dotted areas).

E. Microscopical drawing of a thin section of Silurian grit typical of the Rensselaer grit, from the western edge of the plateau, showing large and small angular grains of quartz (unshaded), four grains of plagioclase, one grain of microcline, one of orthoclase, and several grains of ilmenite (?), all in a matrix of sericite and chlorite.

A

B

C

D

E

The north-south hollow through which runs the road from East Nassau to Hoag Corners separates this last ridge from another east of

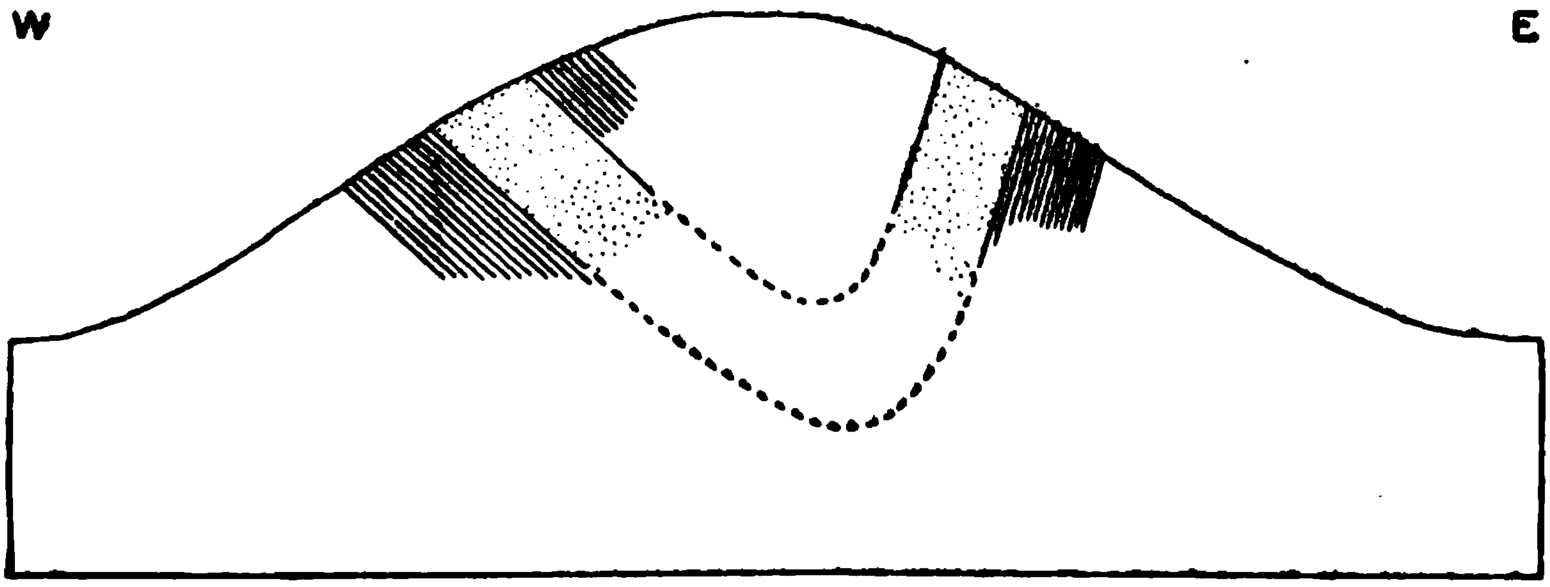

FIG. 5.—Diagram section of ridge southwest of Hoag Corners, in Nassau. Dotted beds, quartzite; lined beds, reddish shale containing small beds of quartzite with casts of organic impressions, etc.

it. Upon this is situated the Coonradt farm. This ridge is separated from the edge of the Rensselaer Plateau by still another hollow.

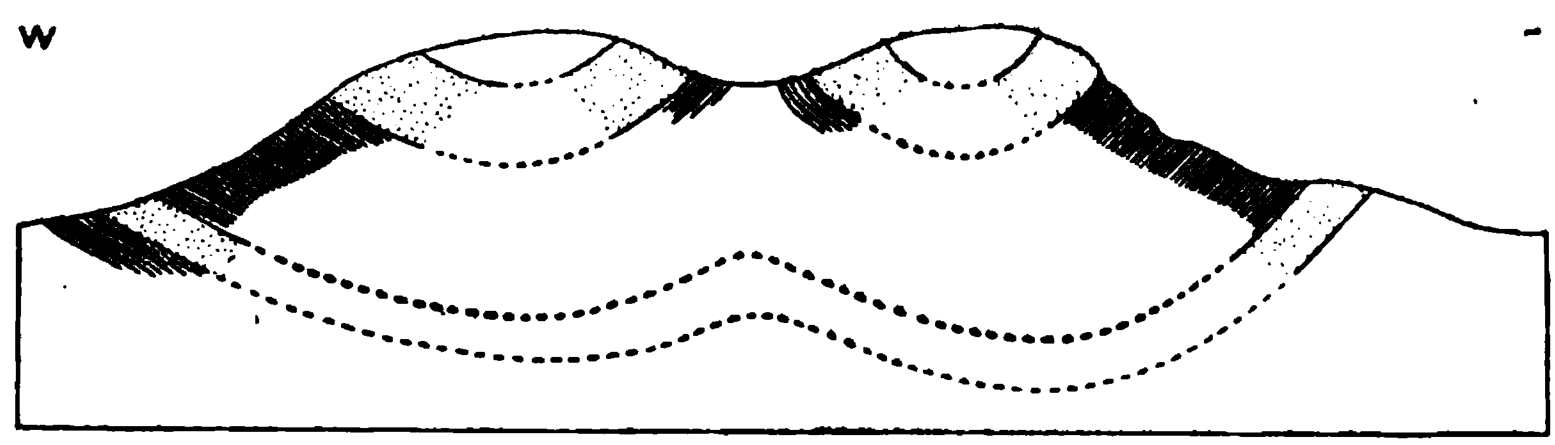

FIG. 6.—Diagram section showing the general structure of the ridge between Tackawasick Creek and Pond and the Rensselaer Plateau, in Nassau. Dotted beds, quartzite; lined beds, shale. Height, about 200 feet.

This ridge also consists of two thick beds of quartzite, each of which is both underlain and overlain by red and green shale with small quartzite beds having casts of organic impressions. (See fig. 7.) The section has been extended eastward across a small hillock in the adjoining hollow to the edge of the plateau.

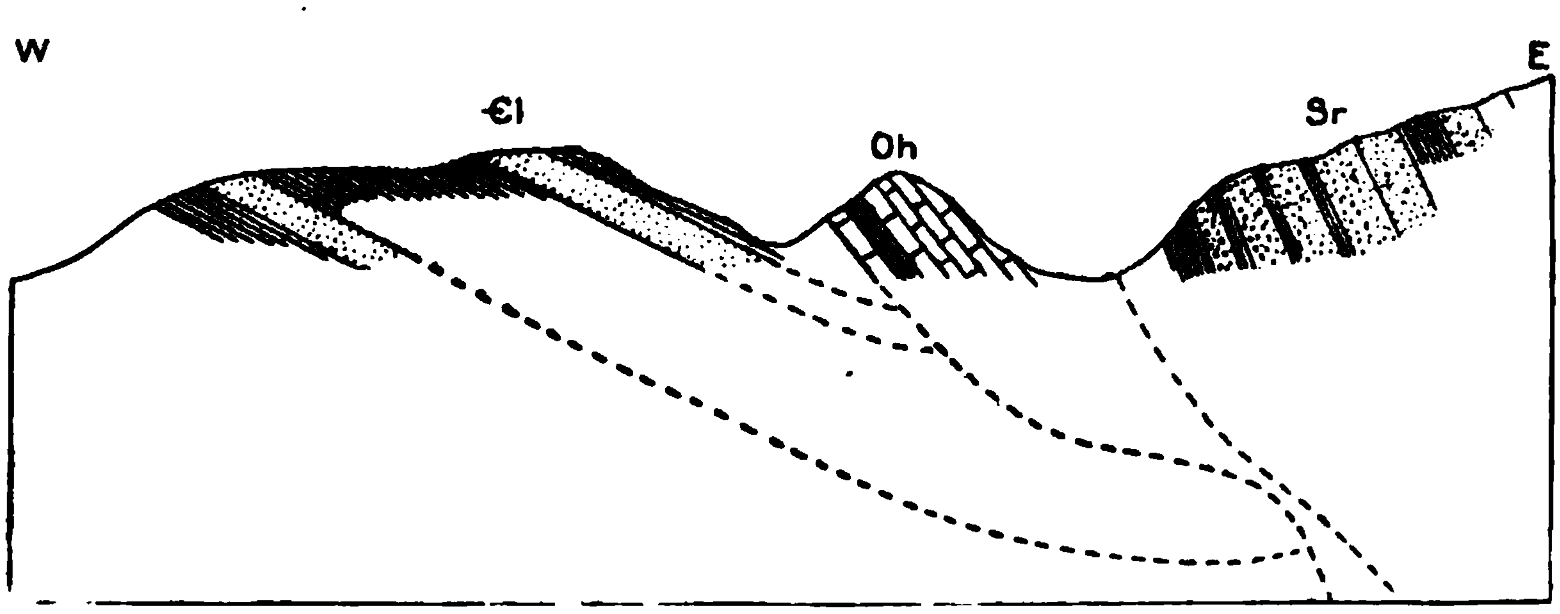

FIG. 7.—Diagram section across the western edge of the Rensselaer Plateau and the second ridge east of Tackawasick Pond, in Nassau, showing the surface relations and the probable structural relations of the Lower Cambrian quartzite and shale (Єl), the Hudson limestone and shale (Oh), and the Silurian Rensselaer grit (Sr). Dotted beds (Єl), quartzite; lined beds, red and green shale with small quartzite beds with organic impressions. Height of western ridge, 90 feet.

A similar series is also exposed on Curtis Mountain, better known locally as Dusenbery Ridge. This can best be observed by ascending the mountain from the saddle between two road forks a half mile south of the western part of Tackawasick Pond. There is first a 40-foot bed of quartzite dipping steeply west and 90°, with red shale under it on the east, followed on the west by 50 to 70 feet of reddish shale with small quartzites with similar dip; then at the head of a ravine there is a ledge, several hundred feet long, of reddish and green shale with small quartzites capped by another bed of quartzite, 15 feet thick, with a low westerly dip. Higher up, after an interval, comes greenish shale with steep westerly dip, recurring at the summit, where it forms an open syncline capped by a slightly calcareous quartzite bed, 10 feet thick, with a gentle southerly pitch. Now, descending the ridge on the west, there is a large body of greenish shale with easterly dip, followed, near the road which skirts the crest on the west, by a bed of quartzite, about 40 feet thick, dipping 45° E., underlain by shale and small quartzites. Within 80 feet of the road is still another bed of quartzite, nearly 10 feet thick, with like dip; and west of that road in a brook (a mile southwest of Tackawasick Pond) is the typical red shale with small quartzites dipping 45° E. and 80 feet thick. These two beds of quartzite with the alternating shale can be traced 1¼ miles north along the crest of Curtis Mountain. A similar series with like dip, evidently belonging to the western part of the same syncline, crops out 1¼ miles south of this last locality, between a small brook crossing the road to Nassau about 3 miles east-southeast of that village, and a corner east of it where three roads meet. Here an upper quartzite, 20 to 25 feet thick, dipping from 45° to 50° E., is underlain by 30 to 40 feet of red and green shale with small quartzites, and these again by another bed of quartzite 8 to 20 feet thick. The same series, but on the eastern side of the syncline, is again exposed on the east side of Curtis Mountain a mile south of the section. Unfortunately the relations are obscured there by overturning and by the coming in of other folds. The general structure of the Curtis Mountain syncline is shown in fig. 8.

Ashley Hill, in Chatham, between Riders Mills and Brainard, lies in the direction of the strike of the syncline on Curtis Mountain. The relations there, however, become perplexing, owing either to faulting or to the syncline being close and followed on both the east and the west by anticlines. Indications of an anticline in the southern part of Curtis Mountain, east of the syncline, have just been pointed out. There is a bench west of the crest of Ashley Hill with a fine exposure of limestone breccia and conglomerate, about 20 feet thick and one-fourth mile long, with the fauna of the *Olenellus* zone.[a] This breccia is associated

[a] See, for petrography, p. 15, and also pp. 312–314 and map, Pl. XCVII, of paper No. 9, p. 11.

with grayish and black shale. At the western edge of the bench is the typical calcareous sandstone with a westerly dip, while east of the fossiliferous belt is a noncalcareous quartzite, probably of the same horizon. In following the strike of the fossiliferous beds northward, down along the ravine to the Kinderhook, the breccia disappears, but the associated black and gray shale crops out occasionally. The calcareous quartzite occurs on both sides of the ravine, with a dip varying according to the overturn of the syncline or as the axis of either adjacent anticline is crossed. This quartzite recurs 1¼ miles north-northeast of Ashley Hill, along the east-west road on the north side of the Kinderhook, and appears to be the same rock as that capping the southward-pitching syncline at the top of Curtis Mountain, 2½ miles north-northeast of Ashley Hill, from which the fossiliferous limestone would thus appear to have been eroded. In the northern part of the bench on Ashley Hill the calcareous quartzite is underlain on the east by a mass of grayish shale, and this by a bed of massive quartzite, 45 feet

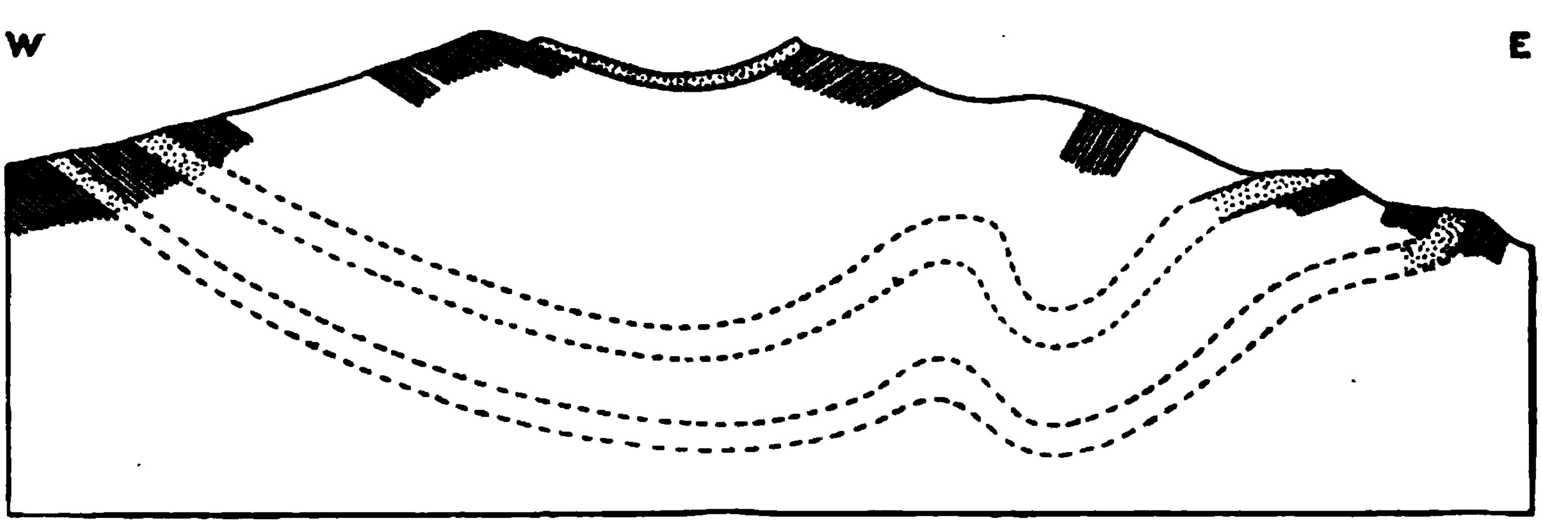

FIG. 8.—Diagram section across the southern part of Curtis Mountain (Dusenbery Ridge), in Nassau, showing the relation of the two thick quartzite beds and the red and green shale with small quartzite beds to the calcareous quartzite syncline at the top. Height, about 400 feet.

thick, dipping 70° W. Farther south, owing probably to an overturn, the dip changes to 55° E., and the gray shale there apparently underlies the massive quartzite. Still farther south is a small outcrop of noncalcareous granular quartzite, already referred to and regarded as the continuation of the calcareous quartzite, and lying east of the fossiliferous bed. East of this is a space of 550 feet of the typical red shale and small quartzites, with the usual casts; 480 feet of these dip steeply east, but the last 70 feet are greatly contorted and have folds pitching 60° S.[a]

East of these are about 150 feet of green shale, then the massive quartzite, 40 feet thick, dipping 65°–70° E., and forming the crest of the hill. About 300 feet farther east is another thick bed of quartzite, dipping 25° E. The gist of all these data is that there is here a bed of calcareous quartzite underlain by shale, and this by two beds of massive greenish quartzite with intervening thicknesses of shale, or by one bed of quartzite doubled in an anticline, the whole closely

[a] See p. 552 and fig. 75 of paper No. 12, p. 11.

resembling the series on Curtis Mountain, but here overlain by the fossiliferous limestone breccia and conglomerate. The general structure of Ashley Hill thus appears to be that shown in fig. 9. That there is a syncline on the western side of the hill is shown by the easterly dip of a bed of quartzite, 8 feet thick, along the highway a half mile west of the top.

About a mile south of Ashley Hill and three-tenths of a mile west of Rayville station, in Chatham, is another important locality. Its

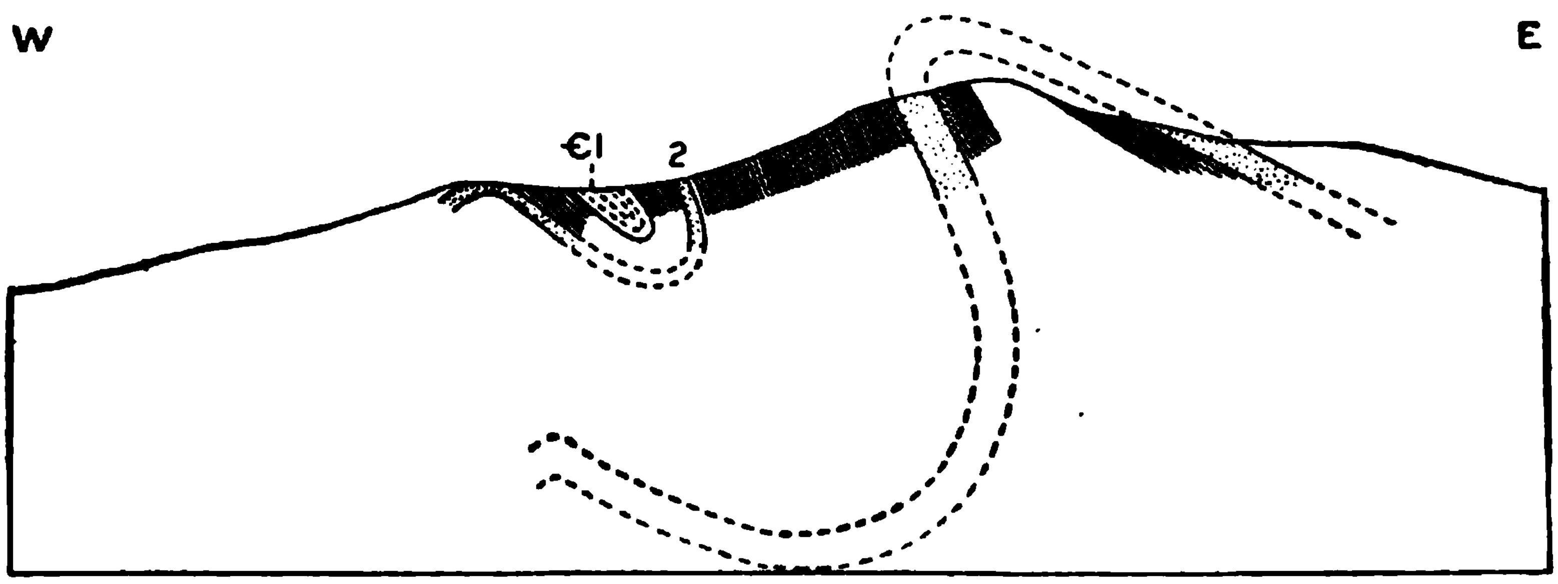

FIG. 9.—Diagram section across Ashley Hill, northeast of Riders Mills, in Chatham, Columbia County, showing the relation of the upper massive quartzite bed and the red shale with small quartzite beds to the calcareous quartzite (2) and the fossiliferous Lower Cambrian limestone breccia (€l).

stratigraphy is shown in fig. 10. Here are two small synclinal hillocks separated by an anticlinal hollow. The fossiliferous Lower Cambrian limestone, about 100 feet thick, is underlain by gray and red shale with small quartzite beds. The eastern syncline has a 5-foot bed of

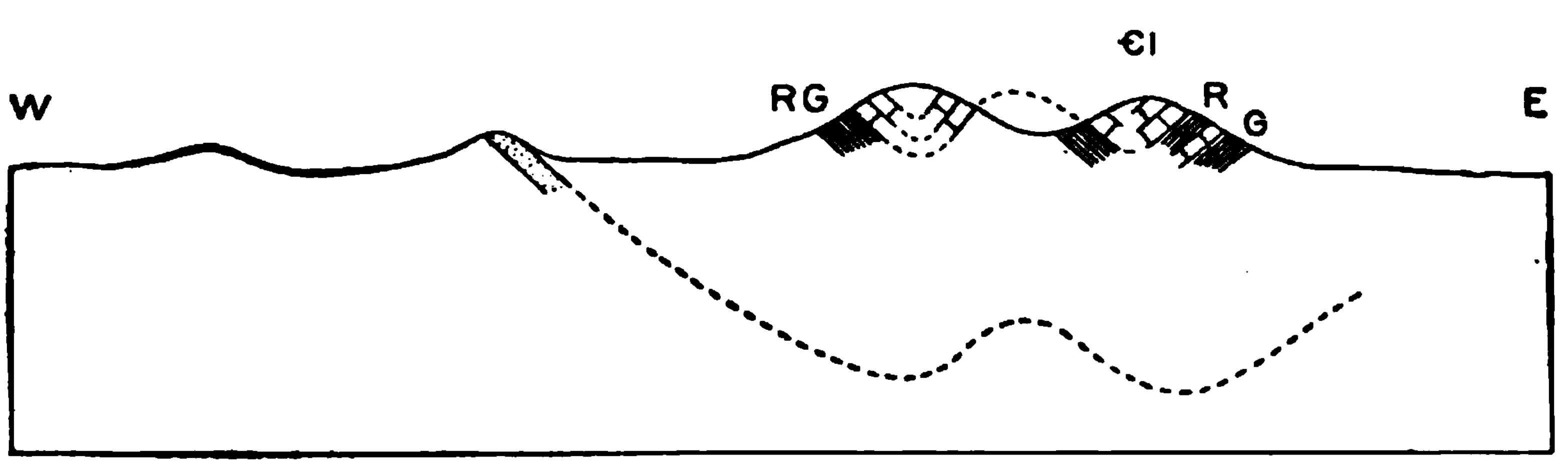

FIG. 10.—Diagram section across the hillock a mile south of Ashley Hill, in Chatham, Columbia County, showing the relation of the quartzite (dotted bed) and of the red shale (R) and green shale (G) to the fossiliferous Lower Cambrian limestone (€l). Height, 60 feet.

brecciated limestone below the red shale, and this is underlain by gray shale with quartzite beds from one-half inch to 2 inches thick. West of these hillocks is a bed of calcareous sandstone dipping toward and probably under them. This tends to corroborate the interpretation of the structure of Ashley Hill as to the relations of the sandstone to the fossiliferous beds.

At a small limestone quarry in East Greenbush, 2 miles south-southwest of Lake Aries and 2 miles southwest of West Sandlake, a mass of

Lower Cambrian bluish limestone or dolomite and calcareous quartz-sandstone, interbedded with dark-gray shale, and a mass of gray shale in contact with it on the east, all dip steeply west; and 200 feet west another outcrop of the same limestone dips east, and there is also easterly dipping shale south of it. These outcrops, taken altogether, indicate the structure shown in fig. 11. Among the limestone strata are large disk-shaped, veined concretions (septaria). Similar Cambrian beds in Nassau contain plano-convex concretions which are

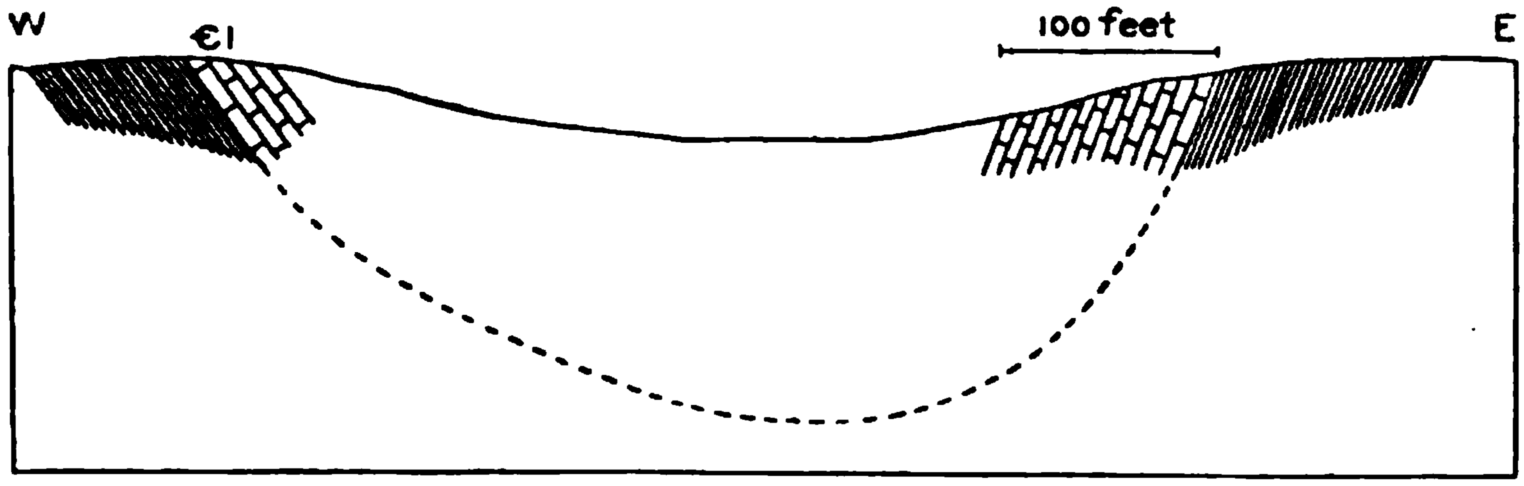

FIG. 11.—Diagram section 2 miles southwest of West Sandlake, in East Greenbush, showing the relation of the Lower Cambrian limestone (€l) and gray shale.

not veined. See paper No. 17, p. 11. The eastern limb of this syncline is again exposed about 800 feet south, but there with an easterly dip.

At a small quarry about 1¼ miles west of Lake Aries, on the south side of the road which follows the north side of the lake, the calcareous sandstone and limestone breccia, with the *Olenellus* fauna, is in contact on the west with greenish shales for one-fourth of a mile along the strike. That this shale here overlies the limestone seems probable from the presence of a small anticline in the limestone along the

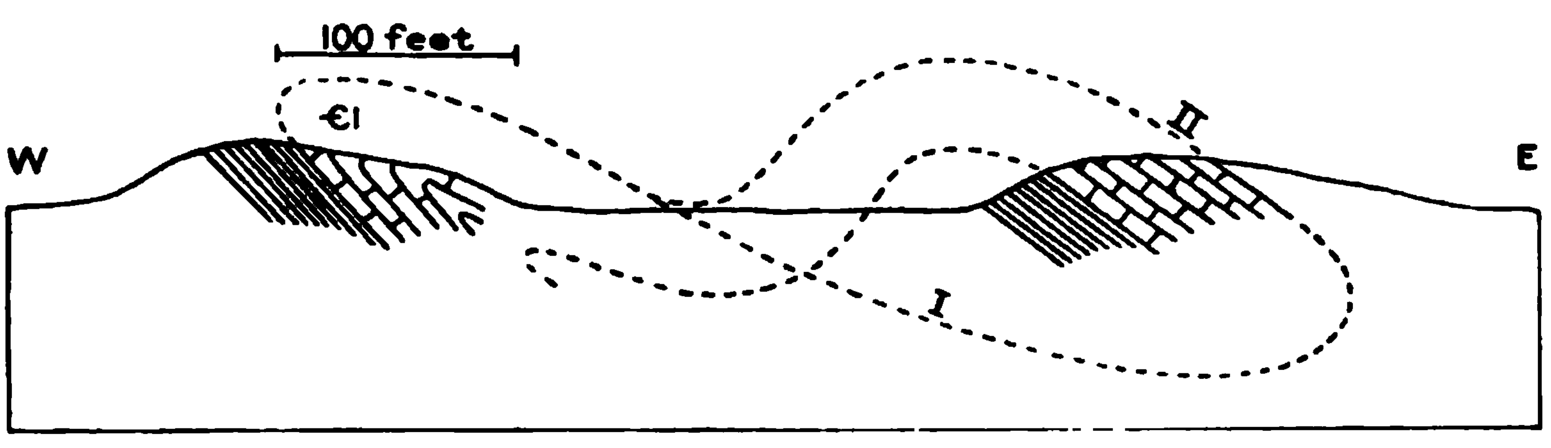

FIG. 12.—Diagram section 2 miles east of Defreestville, in North Greenbush, showing two interpretations of the relations of the greenish shale to the Lower Cambrian fossiliferous limestone (€l),

road, as well as from the almost horizontal dip of the limestone on the east side of the knoll. About 200 feet east of the quarry the shale crops out again, dipping east under beds of calcareous sandstone. The lower part of this shale has small quartzite beds with casts of organic impressions (fig. 12). The evidence as to the relations here is not conclusive. The figure shows two hypotheses: According to I the sandstone would underlie both masses of shale, but according to II it would overlie the shale with quartzites and underlie that at the west without

quartzites. There is also a third possibility—that there is no repetition of beds, but two calcareous and two shale beds.

Foerste found that the Cambrian fossiliferous beds east of Troy,

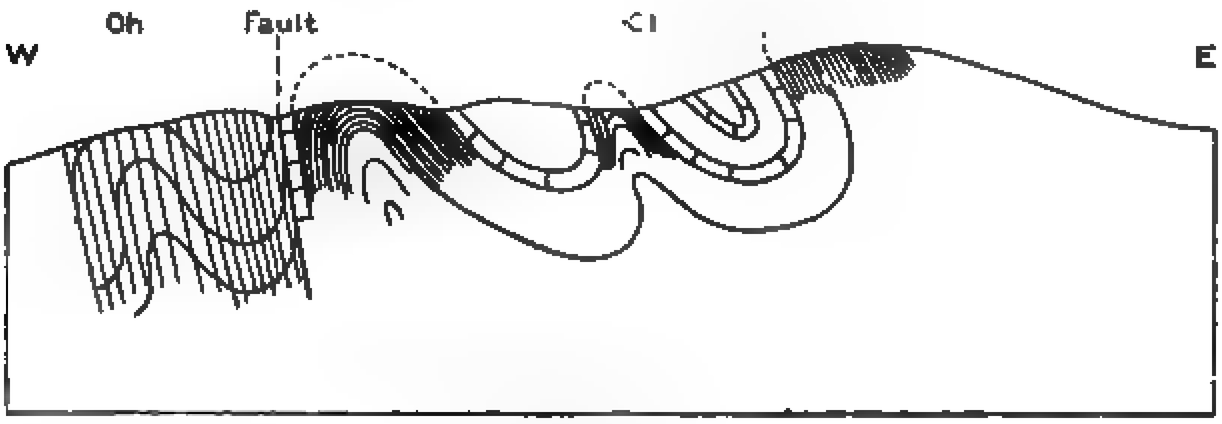

FIG. 13.—Diagram section by Foerste, but slightly modified, showing the probable general relations of the Lower Cambrian fossiliferous limestone (Єl) at Troy to the red and green shale (lined beds) and to the Hudson shale (Oh).

between the 200- and the 400-foot levels, constitute two synclines and two anticlines, underlain by reddish and greenish shale and separated from the Ordovician beds by the overthrust, as shown in fig. 13. He

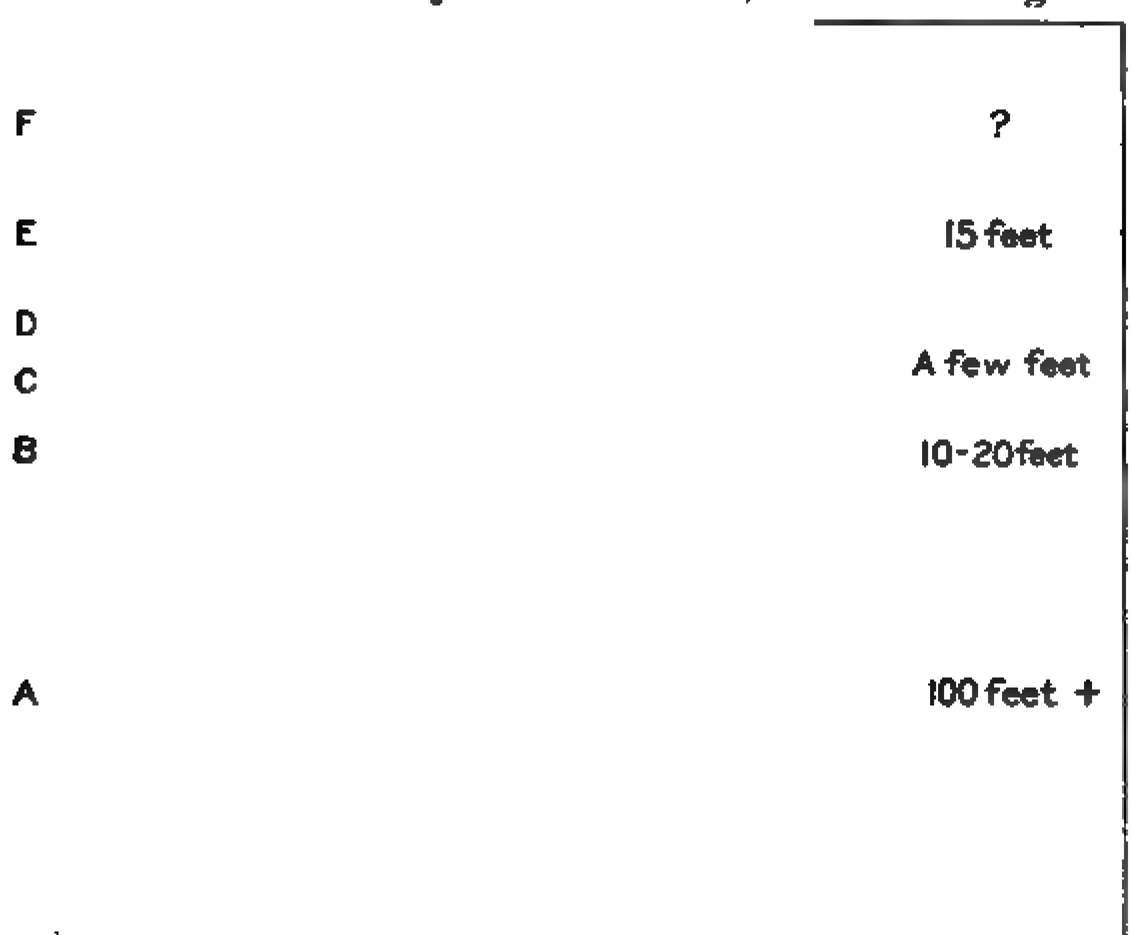

FIG. 14.—Columnar section by Foerste, showing the Lower Cambrian series exposed at Troy. A, red and green shale, in places with small quartzite beds. B, light-blue dolomitic limestone intercalated as fine layers and sometimes forming "brecciation pebbles" in the shale. C, shale with or without limestone beds. D and E, quartz sandstone more or less calcareous, sometimes replaced by sandy shale. F, light-blue dolomitic limestone.

also gives the following section, fig. 14, as representing the Cambrian series of that vicinity.

If the Cambrian beds be followed northward, a different series is found. From Oakwood Cemetery to the vicinity of Melrose the olive

grit, already referred to under "Petrography," crops out occasionally between the Ordovician shale and the Lower Cambrian sandstone, giving a cross section approximately like that shown in fig. 15. This olive grit occurs also at Raymertown associated with the same sandstone. Its exposures near Lake Ida at Troy would bring it, by over-

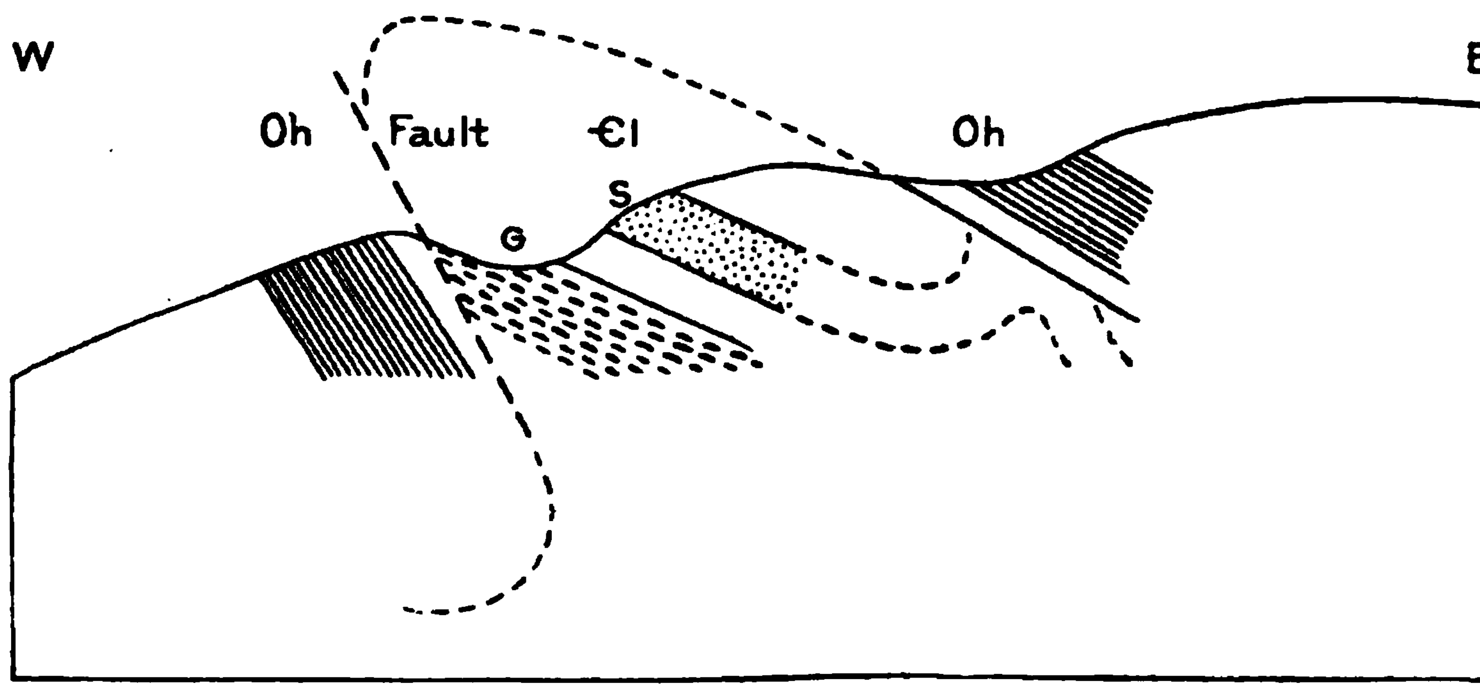

FIG. 15.—Diagram section near Speigletown in Lansingburg, showing the general relations of the olive grit (G) to the Lower Cambrian sandstone (€l) and the Hudson shale (Oh).

turned folding, under the red and green shale with annelid trails and *Oldhamia*, which in turn underlies the fossiliferous Cambrian limestone.

The following section, fig. 16, embodies the writer's observations at and below the dam in the Poesten Kill at Troy. Here reddish, purplish,

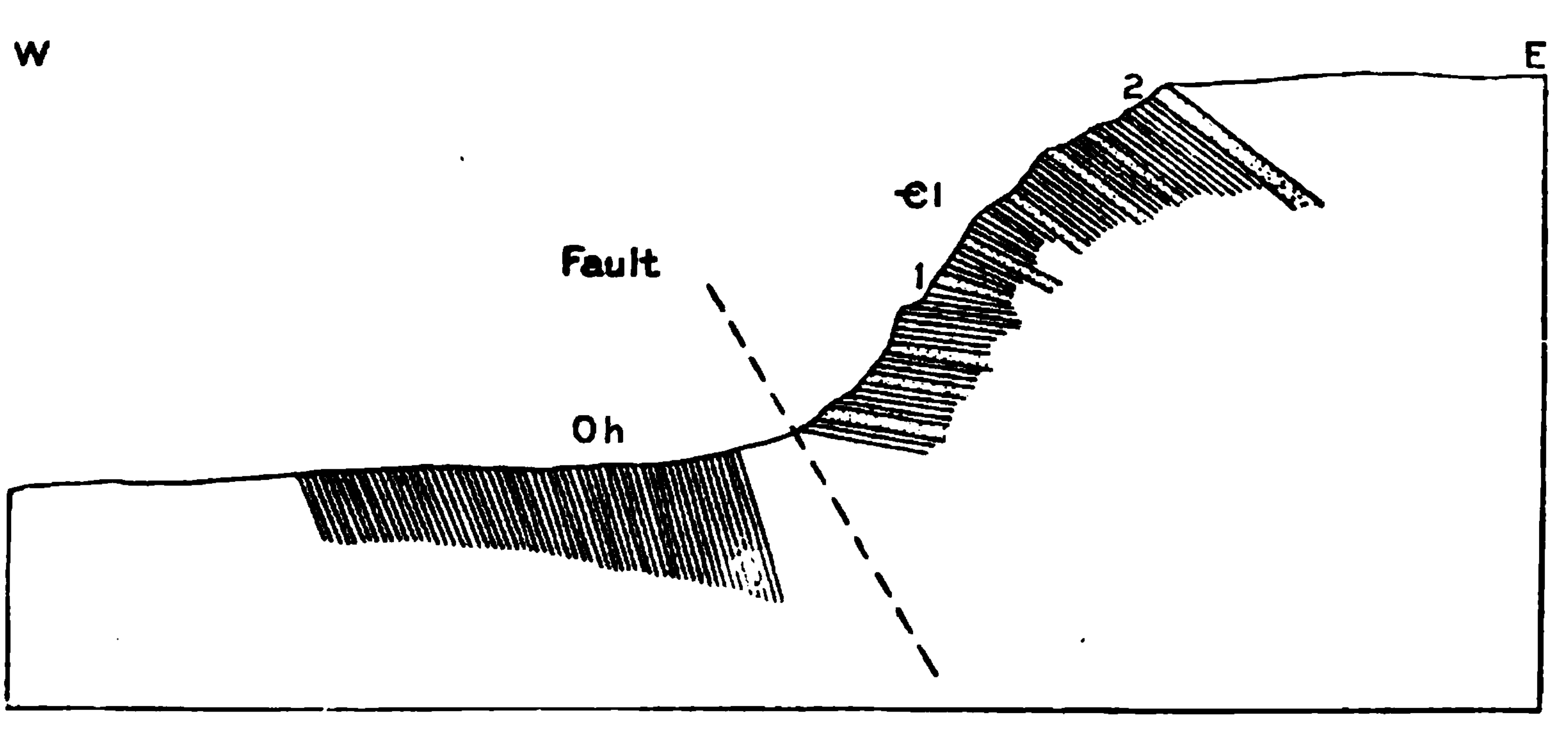

FIG. 16.—Diagram section across the dam in the Poesten Kill at Troy, showing the relation of the Hudson shale (Oh) to the Lower Cambrian red, purple, and green shale (1) and the relation of these to the sandstone bed with Hyolithes and Hyolithellus (2). Height, 100 feet.

and greenish shale underlies a sandstone bed carrying the *Olenellus* fauna, as determined by Mr. Walcott. This colored shale with trails closely resembles that occurring about 2 miles northeast of this locality, which carries *Oldhamia*.

To these sections should be added one at the well-known locality 2 miles south of Schodack Landing, i. e., 7 miles west-southwest from

North Chatham, described by Ford (see paper No. 4, p. 10), as it throws much light on the thickness and order of the Lower Cambrian beds. (See fig. 17.) The section combines the observations at the cliffs, where the thrust plane is not exposed, with those made a third of a mile north, where, however, the beds dip more steeply, the Cambrian 50° and the Ordovician 55°. The dip of the beds in the figure is taken from the cliffs.

These sections will serve to convey a general idea of the Cambrian stratigraphy in this region. Its main features consist of a series of fossiliferous limestone beds, alternating with shale and sandstone, and carrying the *Olenellus* fauna, underlain by gray, red, or purple and green shale, as shown in figs. 11, 14, and 17. On Ashley Hill (fig. 9) this shale is underlain by a calcareous quartzite, and also near Ray-

W E

FIG. 17.—Diagram section showing the relation of the Lower Cambrian limestone (B, C, D) and shale (A) to the Hudson shale (Oh) as exposed at two localities near Schodack Landing in Rensselaer County. B, bedded limestone and nodular limestone in shale (*Olenellus* fauna). C, Conglomerate with a brecciated limestone stratum below it. The pebbles have *Olenellus* fauna. D, Coarse-grained limestone bed with *Olenellus* fauna.

ville station (fig. 10). North of Troy this shale is underlain by an olive grit with or without the intervening quartzite. On Curtis Mountain (fig. 8) the calcareous quartzite is underlain by three horizons of shale, alternating with two of quartzite. These appear again in the ridge south of Tackawasick Pond (fig. 4) and in that east of it (figs. 5 and 6). The red, purple, and green shale which underlies the fossiliferous limestone at Troy (fig. 16) probably belongs to the same horizon as that which 2 miles east of that city carries the *Oldhamia*. The red and green shale with casts and *Oldhamia*, in Nassau, is petrographically identical with that which is interbedded with the two massive quartzite beds (figs. 4, 5, 6, 7, 8, and 9).

All the data in sections 4 to 17 are combined in the following table, to which estimates of thickness, based upon measurements at various localities, have been added, as well as references to the figures.

Table showing the Lower Cambrian series as exposed in Rensselaer County and part of Columbia County, N. Y.

Serial letter.	Description of strata.	Evidence.		Estimated thickness.
		Figure.	Fauna.	
				Feet.
J	Greenish shale	12 ?		50
I	Thin-bedded limestone, or dolomitic limestone, in varying alternations with black or greenish shale and calcareous quartz sandstone. Some of the limestone beds brecciated within the sandstone or shale and forming brecciation pebbles, in places, however, beach pebbles.	9, 10, 11, 12, 13, 14, 17.	*Olenellus* fauna	[a] 20–200
H	Greenish, reddish, purplish shale, in places with small beds of more or less calcareous quartzite.	10, 11, 13, 14, 16, 17.	*Oldhamia*, annelid trails.	25 ?–100+
	At Troy, in upper part a 2½-foot bed of calcareous sandstone.		*Hyolithes* and *Hyolithellus*.	
G	Granular quartzite, in places a calcareous sandstone.	8, 9, 10		10–40
F	Olive grit, metamorphic, usually weathering reddish; absent at south.	15	Traces of ?	18–50
E	Greenish, or reddish and greenish, shale with small quartzite or grit beds.	7, 8, 9	Casts of impressions, *Oldhamia*.[b]	65–535
D	Massive greenish quartzite, in places very coarse.	4, 6, 7, 8, 9		10–50
C	Reddish and greenish shale with small beds of quartzite or grit (rarely up to 5 feet thick).	4, 5, 6, 7, 8	Casts of impressions, *Oldhamia*.	30–80
B	Massive greenish quartzite, in places very coarse.	4, 5, 6, 7, 8		8–40
A	Reddish and greenish shale with small beds of quartzite or grit, from 1 to 12 and, rarely, 24 inches thick.	4, 5, 6, 7, 8	Casts of impressions, *Oldhamia*.	50–80

[a] Usually 50. [b] *Oldhamia* occurs in A, C, or E, and quite possibly in all three.

Minimum, 286. Maximum, 1,225+.

AREAL AND STRUCTURAL RELATIONS.

The greenish and reddish shale which makes up the greater part of the Cambrian area belongs to the several shale horizons A, C, E, H, I, and J. The shales of these horizons can be distinguished only where they come in contact with either the fossiliferous limestone or the two beds of massive quartzite. As some areas of Beekmantown shale may yet be found, here and there, within the Lower Cambrian area, the age designation of that area on the map should not be strictly interpreted. The finest exposures of the reddish and greenish shale with small quartzites having organic impressions (horizons A, C, E), which either carry *Oldhamia* or are likely to do so, are in the eastern half of the Cambrian area as indicated on the map. Most of the exposures of the massive quartzite of horizons B and D are in the township of Nassau.

There is a considerable area of the greenish shale with small quartzite and small limestone beds, extending from a point 2 miles northeast of Melrose, on the west, to Tomhannock and Valley Falls

on the east, and north to the Washington County line and beyond, which is regarded as belonging to the Cambrian. Mr. Ruedemann's Upper Cambrian fossil locality at Schaghticoke (paper No. 20, p. 11), for reasons given on page 31, is regarded as being in an outlier of Beekmantown.

As the Middle Cambrian is absent and the Upper Cambrian essentially so, the Lower Cambrian is here unconformably related to all the formations which adjoin it as well as to the outliers which rest upon it. On the west it appears to be thrust over onto the Hudson by a fault which is clearly present near Schodack Landing on the south and at Bald Mountain, in Greenwich, on the north, but which may be inconsiderable here, and, in places, disappear altogether, being simply an unconformity and an overturned fold. The observed relations of the Lower Cambrian to the Hudson have been shown in figs. 13, 15, 16, and 17, and they will be further considered in the study of that formation. Its relations at one point to the Rensselaer grit are shown in fig. 7, and will also be further described under that heading. Its relation to the Beekmantown will be considered more fully under the next heading.

BEEKMANTOWN SHALE.

FOSSIL LOCALITIES.

Mr. Prindle found some graptolites in very small grayish arenaceous layers, interbedded with small layers of finely banded quartzite, cropping out on either side of the road running from West Sandlake to Defreestville, about a mile southwest of Lake Aries, in North Greenbush, and again in similar rock at a point about 2½ miles north-northeast of the first locality and a mile south of Wynantskill, in the same town. These were referred to Mr. Charles Schuchert, who identified them provisionally as *Graptolithus quadribrachiatus* (Hall), *G. bryonides* (Hall), *G. bifidus* (Hall), *Clonograptus flexilis* (Hall), *C.* near *salteri* (Hall), *Dictyonema murrayi* (Hall), *D.* near *irregulare* (Hall), and pronounced them "faunally much like the Quebec (Levis) graptolite zone." Mr. Prindle soon afterwards found similar rocks with similar graptolites at a point a mile southwest of Wynantskill, and again at another point 1½ miles west-southwest of that village. In 1895 the writer found some graptolites at a point 2 miles northeast of Raymertown village, in Pittstown, in small micaceous, calcareous, quartzose, finely banded, grayish beds covered with trails. These were referred to Mr. R. R. Gurley, who identified them as *Dichograpsus* sp., *Dichograpsus?*, and *Tetrograpsus* or *Dichograpsus*, and called the horizon Calciferous, i. e., Beekmantown.

Mr. Ruedemann's new graptolite localities in the Deep Kill, east of Grant Hollow, in Schaghticoke (paper No. 19, p. 11), appear to be in one or two masses of Beekmantown shale separated from the Hudson shale

on the west by an outcrop of Cambrian breccia, noted by the writer in 1899. Typical Cambrian rocks occur also one-fourth of a mile southwest and three-tenths of a mile northeast. The fauna of his eastern outcrop, which measures 40 feet from east to west and is separated from the western one by 825 feet of drift, he regards as Beekmantown or Chazy, and in any case as more recent than that of the other. This eastern outcrop may be continuous with—i. e., its beds may pass under—the Hudson outlier to which Rice Mountain belongs.

In some shale at Schaghticoke Mr. Ruedemann found *Dictyonema flabelliforme* (Eichwald) and *Clonograptus proximatus* (Matthew), which he regards as Upper Cambrian (see paper No. 20 on page 11), but on page 936 he observes:

> It is evident that there was no difference or break whatever in physical conditions from the time of the deposition of these Cambrian beds to that of the lower Siluric beds.

As these forms are not quite conclusively or exclusively Upper Cambrian, and as the genera *Clonograptus* and *Dictyonema* occur mingled with Beekmantown graptolites a mile southwest of Wynantskill, as shown on page 30, this fauna is regarded as essentially Beekmantown, with possibly a few surviving Upper Cambrian forms. This locality is, therefore, shown on the map as occurring in a small area of Beekmantown shale resting upon the Lower Cambrian. It should be added that the surfaces of the fossiliferous Beekmantown beds in North Greenbush are marked by coarse branching casts of organic origin.

All these localities are shown on the map.

PETROGRAPHY.

The finely banded quartzite beds which mark this horizon, when examined microscopically, prove to consist of angular grains of quartz, with rare fragments of plagioclase and occasional scales of muscovite. The banding is due to fine stringers of sericite stained with limonite and containing here and there what appear to be carbonaceous particles. These undulating stringers of sericite are from 0.12 to 0.62 mm. apart. In places the beds are very calcareous. The associated grayish and greenish shale was not examined microscopically. Outwardly it resembles the Cambrian shale of the same colors.

STRATIGRAPHY AND AREAL AND STRUCTURAL RELATIONS.

Several areas of Beekmantown shale are shown on the map. That on the south side of Mount Rafinesque, in Brunswick, and three of those in North Greenbush, were identified only petrographically. More minute exploration may bring others to light. From the relative position of the areas in North Greenbush to the Cambrian fossil

localities, the outlier of Hudson shale with Normans Kill graptolites is probably surrounded and underlain by Beekmantown shale, and that by the Lower Cambrian. Its structure would be a complex syncline. Near Wynantskill, however, the Beekmantown seems to occur in a narrow fold. In Pittstown the areal relations indicate a westwardly overturned anticline of Beekmantown from which the Hudson has been eroded. Whether the Beekmantown always intervenes here between the Lower Cambrian and the Hudson is uncertain. The map indicates the formation only where it has been identified.

The exposures of Beekmantown shale are not sufficiently satisfactory to be represented in sections. At the first-mentioned locality, which is about 200 feet west of the tollgate, the greenish-gray shale, with small beds of finely banded quartzite, measures about 100 feet across the strike, followed on the west by 93 feet of similar shale not banded, which may be Cambrian. The whole series is in minor folds more or less overturned to the west. The fossils were found 25 feet east of the boundary between the two varieties of quartzite. The situation of the outcrop west of the tollgate in relation to the Normans Kill graptolite locality north of the road, and of this to another outcrop of Beekmantown east of it, indicates a synclinal structure here for the Beekmantown, with the Hudson shale overlying. At the second locality (south of Wynantskill) the outcrop is about 80 feet wide from east to west; the beds strike N. 25° E. and are in minor folds. Limestone, probably Cambrian, occurs in close proximity. At the locality a mile southwest of Wynantskill from 30 to 40 feet of this shale and quartzite overlie the fossiliferous Cambrian limestone.

At the locality northeast of Raymertown, in ascending the brook from the road on the west, the following series is crossed: Green shale with small quartzite beds, underlying light-green, red, and purplish shale, striking N. 30° E. and dipping 45° E. These colored beds are covered with trails, etc. Farther up comes red shale with small calcareous quartzite beds. In a gulley a few hundred feet north of the creek is an outcrop of typical Hudson grit. Farther up the main creek is the gray shale with small calcareous quartzite beds containing Beekmantown graptolites. About a half mile north, in the direction of the strike, is the black Hudson shale with graptolites, and 40 feet west of this is the red and green Hudson shale which was crossed at the beginning of the section.

In all of these localities the close proximity of the Beekmantown beds to both the Lower Cambrian and the Hudson beds is noticeable. This signifies: (1) An unconformity between the Lower Cambrian and the Beekmantown by the absence of the Middle Cambrian and, as far as present evidence goes, of the Upper Cambrian also. (2) An unconformity between the Beekmantown and the Trenton, the Chazy being

absent, if not the base of the Trenton also. Mr. Ruedemann is not quite sure of the Chazy age of the Deep Kill fossils (his zone C), but is sure of the Chazy age of the fossils in certain limestone pebbles in the conglomerate of Rysedorph Hill (see pp. 89, 107, of paper No. 16, p. 11), and Chazy limestone beds have not yet been found in this tract.

The thickness of the Beekmantown shale at the localities described in this paper is roughly estimated at about 50 feet. As there is a possibility that some of the green shale without banded quartzites and without fossils belongs to this formation, this estimate should be taken as a minimum. Mr. Ruedemann estimates it as high as 200 or 300 feet on the Deep Kill (p. 550 of paper No. 19, p. 11).

HUDSON SHALE AND HUDSON SCHIST.

As the schist of the Taconic Range is the metamorphic equivalent of the shale and grit of the valley, they will all be here treated as one formation.

FOSSIL LOCALITIES.

Twenty-five fossil localities are shown in the Hudson areas. The fossils collected at the locality one-half mile southwest of Lake Aries, in North Greenbush, were identified by Mr. Charles Schuchert as *Diplograptus* cf. *angustifolius*. From a point a mile north-northeast of that he identified *Didymograptus sagittarius*, *Lasiograptus mucronatus*, as well as *Diplograptus* cf. *angustifolius*. Graptolites also occur a half mile west of this last place. From a place on the north bank of the Hoosic, a mile west of Schaghticoke, he identified *Climacograptus bicornis*, and from the locality near the paper mill on the Moordener Kill, three-fourths of a mile north-northeast of Castleton, in Schodack, the following: *Didymograptus sagittarius*, *Diplograptus* cf. *angustifolius*, *Lasiograptus mucronatus*, *Dicellograptus sextans*, *Dicranograptus ramosus*, *Climacograptus bicornis*, and *C. parvus*.[a]

Graptolites were also found at the five localities indicated in Pittstown and two in Schaghticoke, near Melrose. They were found in 1890 by Foerste south of and in the railroad cut between 1 and 2 miles north of Chatham. (See Pl. XCVII of paper No. 9, p. 11.)

In the Boston and Maine Railroad cut near the Deep Kill, a mile southwest of Melrose, in Schaghticoke, a very thin calcareous bed in the Hudson shale carries brachiopods, crinoids, and polyzoa.

There are also important conglomerates in these shales. The Rysedorph Hill locality in East Greenbush has been exhaustively described by Mr. Ruedemann. (See paper No. 16, p. 11.) Mr. Prindle, when visiting this locality in 1893, noted that the pebbles of the conglomerate

[a] Ruedemann gives from this locality: *Diplograptus foliaceus*, *D. angustifolius*, *Climacograptus bicornis*, *Lasiograptus mucronatus*, and *Corynoides calicularis*. (See p. 544 of paper No. 15, p. 11.)

were a blue limestone, that the cement on exposed surfaces was yellowish, and that both pebbles and cement were fossiliferous. On Van Denburg Hill, in Schodack, about 5½ miles south-southwest of Rysedorph Hill, is a limestone breccia (and conglomerate ?) containing Ordovician brachiopods and crinoids.

On the Moordener Kill, 200 feet upstream from the graptolite locality already mentioned, Mr. Prindle noted 1-foot blocks and small fragments of limestone conglomerate in a dark-gray fossiliferous shale. The pebbles of this conglomerate, as well as its cement, contained Ordovician brachiopods and crinoids. Two hundred feet farther upstream a similar bed of conglomerate was found, producing a waterfall 10 feet high. He was unable to determine whether this was a lenticular mass within the shale or the core of an anticline. Here a vertical cliff of shale 200 feet high, containing similar pieces of fossiliferous conglomerate, forms the right bank of the stream. About 200 feet farther upstream, and 50 feet below the upper falls, is a third bed of conglomerate, 12 feet thick, also carrying brachiopods. Between this point and the falls is a fourth bed, separated from the last by about 25 feet of shale. About 500 feet beyond the upper falls Mr. Prindle found a fifth mass of conglomerate, 50 feet thick, in the shale. This, like the others, contains pebbles of bluish fossiliferous limestone in a brownish cement. It afforded, however, no clue to its structure. Mr. Ruedemann describes two of these conglomerates and gives a list of fossils showing both pebbles and cement to be of Trenton age.[a] It was not determined whether these conglomerates were distinct beds or repetitions of one or more beds. A half mile northeast of Schodack depot, on the same kill, the Hudson grit and shale contain thin beds, with crinoids and polyzoa.

Passing now to the Ordovician on the east side of the Cambrian belt, there are several fossiliferous limestone localities, one at the foot of the Rensselaer Plateau in Nassau, a half mile northeast of Tackawasick Pond, the structural relations of which are shown in fig. 7 (p. 21). This locality was first described on pp. 311, 312, and the map Pl. XCVII, of paper No. 9, p. 11. The fossils found here by Foerste were Trenton: "*Monticulopora*, *Murchisonia*, *Calymene*, an orthis of *O. plicatella* type, and crinoid stems." This limestone contains a bed of gray shale, and this shale recurs at the south. Both are, therefore, regarded as Trenton.

Another locality is in Chatham, about midway between Sutherland Pond and the Chatham and Lebanon Valley Railroad. This appears to be about a mile east of one of Bishop's localities and is probably connected with it. (See p. 440 of paper No. 5, p. 10). The limestone is interbedded with greenish rusty shale and dolomite. A poorly pre-

[a] See pp. 544-546 of paper No. 15, p. 11.

served gastropod and a loosely laminated *Stromatocerium*, as determined by Mr. E. O. Ulrich, were found here. A wall by the road here is made of fossiliferous limestone. Adjacent to this locality on the east and south is grayish-greenish shale. This limestone seems to recur a half mile south of Old Chatham, in a hillock known as Tonys Nose, there also associated with dolomite. At the top, limestone fragments, apparently from an outcropping grayish-greenish shale, contain traces of fossils. Between these two localities is a ridge composed of two thick beds of quartzite, alternating with red and green shale with small quartzites, typical of horizons B, C, D, E, of the Lower Cambrian series.

The last locality is one of Bishop's, 1½ miles north of Chatham, where Foerste obtained *Leptaena sericea*, a *Murchisonia*, a *Pleurotomaria*, etc. (See p. 315 and Pl. XCVII of paper No. 9, p. 11.) Bishop mentions from here, and from a point a mile south, besides the above, *Strophomena alternata*, a doubtful *Maclurea*, an *Ophileta*, an undeterminable *Orthoceras*, and the polyzoon, *Ptilodycta*. The Hudson grit, a half mile west of Schaghticoke, on the south bank of the Hoosic, and again a half mile south of Schodack depot, on the railroad, has organic impressions preserved as casts, somewhat similar to those occurring in the quartzite beds of the Lower Cambrian series.

PETROGRAPHY.

The unaltered part of the Hudson formation consists of black, gray, greenish, and reddish shale, with interbedded grit; black, white-weathering, cherty-looking beds; limestone, and limestone conglomerate; and in places small beds of quartzite.

The most typical and significant of these rocks is the grit. This is a loose aggregate of angular grains of quartz, plagioclase feldspar, scales of muscovite, and graphite, together with particles of several clastic rocks, all held together by a carbonaceous, calcareous, and rarely sericitic cement. As the writer has already published microscopical descriptions of this rock, based upon a number of thin sections,[a] it will be sufficient, in order to convey an idea of its general character, to add a microscopical drawing (Pl. II, *D*) and also to call attention again to the significant occurrence in it of grains of clastic rocks. A description of a thin section of this grit from a point 100 feet below the dam in the Poesten Kill, at Troy, is here repeated from paper No. 13, p. 11. The rock contains grains of quartzite, limestone with veins of calcite, grains consisting of quartz fragments, muscovite scales without orientation, chlorite, and rutile needles (which indicate a slate in parallel section, or else a shale), a grain of micaceous quartzite, a grain of stratified carbonate rock with quartz grains—i. e.,

[a] See pp. 187, 188 of paper No. 13, p. 11.

quartzose limestone or dolomite—and a grain of slate with aggregate polarization, containing quartz grains, chlorite, and tourmaline.

At the western foot of Rice Mountain, 1¼ miles south-southwest from Grant Hollow and about 700 feet southeast of the road corner, in the town of Schaghticoke, a small excavation has exposed Hudson grit strata, about 30 feet thick, containing a few inches of conglomerate, the pebbles of which scarcely exceed one-sixth of an inch in diameter. These pebbles prove to be mostly fine-grained dolomite, but there are also pebbles of slate, carbonaceous shale, carbonaceous sandstone, cryptocrystalline quartz, vein quartz, and plagioclase and orthoclase feldspar. The grains of clastic rock show that during the deposition of the Hudson grit certain slates, shales, limestones, dolomites, quartzites, and sandstones were above water at no very great distance. At a quarry south of the Poesten Kill, in Troy, the grit contains minute globular masses of anthracite, each surrounded by a film of chalcedony.

The cherty-looking beds referred to crop out at several points. At Grandview Hill, in East Greenbush, this rock consists of a carbonaceous matrix containing angular fragments of quartz and plagioclase and scales of muscovite. Its weathering white may be due either to the loss of carbon or to the kaolinization of a fine feldspathic cement.

In a small ravine 2 miles west-southwest of East Greenbush, south of the Boston and Albany Railroad crossing, the Hudson shale contains small irregular beds or nodules of fine-grained calcareous quartzite, in which the particles are angular and almost entirely quartz, with an occasional grain of plagioclase or zircon or a flake of muscovite.

The metamorphic part of the Hudson formation consists of the sericite-schist which constitutes the Taconic Range. This has been so often described[a] that it will be sufficient to state that it is sometimes black from the presence of graphite, or greenish from the abundance of chlorite, or purplish from the addition of hematite. In Chatham the transition from shale to schist, in passing from the west to the east, is so gradual that it is often difficult in the field to determine whether a given rock is a shale or a phyllite. In Austerlitz, a quarter of a mile south of Redrock, the schist contains a bed of slightly chloritic quartzite, 20 feet thick, with pebbles of quartz up to an eighth of an inch in diameter.

STRATIGRAPHY.

The general structure of the strip of the Hudson formation between the Hudson River and the Cambrian boundary, in at least its narrower part, is shown at a quarry between Troy and South Troy, where an acute anticlinal core, slightly overturned to the west, forms the center of a mass of shale and grit about 400 feet wide, measured across the

[a] See pp. 303–306 of paper No. 9, p. 11, and Mon. U. S. Geol. Survey, vol. 23, pp. 182–184.

strike. At the north end of the quarry the east limb of the fold dips 60° E. and the west limb 80° E., but at the south the anticline is nearly erect. The folds in the wider part, however, are not all of this character, for at an old quarry a half mile southwest of Defreestville, or 2 miles northeast of Rensselaer, a gentle anticline of grit and shale, about 100 feet in diameter, is exposed.

The order and thickness of the Hudson beds are difficult to determine. This is in consequence not only of the frequent overturned folding, as shown above, but also because of the horizontal transition of red and green shale into each other and probably of several other members of the series, the interbedding, the possible difference in age indicated by different graptolite faunas, as shown by Ruedemann (paper No. 15, p. 11), and also the unconformities shown by the limestone conglomerates (paper No. 16, p. 11).

The following table embodies such approximations as to the order and thickness of this formation as the data, obtained during these studies and from the literature, seem to warrant:

Table showing the Hudson formation as exposed in Rensselaer County and the northeastern part of Columbia County, N. Y.

Description of strata.	Fauna.	Estimated thickness.	Age.	Metamorphic equivalent.	Estimated thickness.
Black shale with arenaceous limestone, etc.[a]	Diplogr. amplexicaulis.[b]	Feet. 1,200-2,500?	Trenton.	Sericite-schist, black, green, or purple, in places with greenish quartzite up to 20 feet thick.	Feet. 1,000-2,000
Black and gray shale with interbedded grit.[c]	Normans Kill graptolite fauna.				
Similar shale with limestone and limestone conglomerate.	Trenton fauna in limestone and cement of conglomerate.[d]				
Black, siliceous, white-weathering, "cherty-looking" shale.[e]	....				
Reddish, purplish, greenish shale, with small quartzite beds.[e]	....				

[a] See Ruedemann, pp. 585-587, stations 24, 25, 26, of paper No. 15, p. 11.
[b] See as above for other fossils.
[c] Rarely with small beds of quartzite.
[d] The pebbles of this conglomerate contain Trenton, Chazy, and Lower Cambrian fossils. See paper No. 16, p. 11, and Ford, paper No. 3, p. 10.
[e] The vertical relations of the colored shale and the black siliceous shale to each other and to the black and gray shale with Normans Kill graptolite fauna are not clear. They are all intimately associated. The greenish shale sometimes includes small limestone beds.

AREAL AND STRUCTURAL RELATIONS.

The Hudson formation, as shown on the map, occurs on both sides of the Lower Cambrian belt, and it also forms two isolated areas of more or less complex synclinal structure within and upon it. Some of its structural relations are shown in figs. 7, 13, and 15-17. The Hudson beds are frequently separated from the Lower Cambrian by a few feet of Beekmantown shale. Whether this shale always intervenes in eastern New York has not yet been determined. In any case,

it is here unconformably related to the underlying formations either by the absence of the Chazy and the Middle Cambrian, very probably also of the Upper Cambrian, or by the absence of these and the Beekmantown, and in both cases possibly also by the absence of the lowest Trenton. An unconformity to older sedimentary formations is indicated by the pebbles and grains of slate, limestone, dolomite, and quartzite within the grit, as shown under "Petrography," and this has also been paleontologically corroborated by the conglomerate interbedded with the grit, the pebbles of which contain Lower Cambrian and Chazy fossils.

That the relations on the west side of the Cambrian belt are not only those of unconformable deposition but of a more or less continuous overthrust is rendered somewhat probable from the situation of the overthrust near Schodack Landing (fig. 17) and of that at Bald Mountain[a] in Greenwich, 47 miles north-northeast of the former, as well as from the general direction of the Cambro-Hudson boundary between them. It is to be noted also that at the outlet of the pond in Oakwood Cemetery in Lansingburg the black cherty beds of the Hudson underlie the olive grit (horizon F) of the Lower Cambrian, from 110 to 340 feet of the Lower Cambrian being absent either through faulting or through pre-Hudson erosion.

For these reasons it is assumed that in consequence of a westwardly overturned fold, which is frequently ruptured, the Lower Cambrian here usually overlies the Hudson—i. e., the Trenton or middle part of the Ordovician. The east-west course of the Cambro-Hudson boundary east of Van Denburg Hill corresponds roughly to a change in the strike of the Hudson beds. It is uncertain whether the overthrust follows this bend or maintains its northerly course or is interrupted.

The isolated mass of Hudson shale in Brunswick, Lansingburg, and Pittstown, amply identified by graptolite localities and by the typical black and red shale, grit, and cherty-looking beds, is almost surrounded by typical Cambrian beds with several fossil localities. It has Beekmantown beds at two points, one on either side of it. The reason for drawing the boundary here different from that on Mr. Walcott's map[b] is that the shale with small beds of quartzite which crops out north of the graptolite shale has a general resemblance to the Cambrian shale, although no Lower Cambrian fossils have as yet been found north of the latitude of Tomhannock village in the area of this map. The east-northeast to west-southwest trend of Mount Rafinesque is due to change in the strike of the Hudson shale. Less than a mile

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[a] See paper No. 6, p. 11; Walcott, C. D., Am. Jour. Sci., 3d ser., vol. 35, p. 317, fig. 12. The continuation of this fault was retraced in 1902 by Mr. Fred H. Moffit, then the writer's assistant, from Bald Mountain, Greenwich, in a northerly direction 10 miles into Argyle.

[b] See Pl. III of paper No. 6, p. 11.

east of Chatham Center there is an outcrop of the black cherty-looking beds and red shale of the Hudson formation striking N. 10° E., but a mile farther southeast the gray shale of the Cambrian crops out. At Malden bridge, 4 miles north-northeast of the first of these localities, the following series is exposed in the bed of the Kinderhook: Beginning on the east, 40 feet of gray shale and grit, 24 feet of black shale and limestone, followed by over 70 feet of shale, with a few calcareous beds and coarse, gritty beds. As the age of these beds is uncertain and as the area between them and the outcrops east of Chatham Center was not explored, there may be a tongue of Hudson-Trenton extending up this valley. This area has therefore been left uncolored.

The relations of the Hudson formation to the overlying Rensselaer grit of the Silurian are shown in the section, fig. 7 (p. 21), which crosses the contact of the two formations in Nassau, near Tackawasick Pond, and on the map, Pl. I (p. 12), which shows an outlier of typical Rensselaer grit and conglomerate resting upon the Hudson schist 2 miles northeast of Spencertown, in Austerlitz.

The small mass of unfossiliferous limestone southeast of Pike Pond, in Nassau, is probably of Hudson (Trenton) age also, and immediately underlies the grit of the plateau. It may be continuous with that about 3 miles south.

RENSSELAER GRIT.

PETROGRAPHY.

With the exception of faint annelid trails at one point, no fossils have as yet been found in this formation. Its petrography has been already so fully treated in print that little need be added.[a] Its petrographic characteristics, in brief, are as follows: A dark-green, tough, generally thick-bedded, often calcareous, crystalline, granular rock, with visible quartz and feldspar grains, and traversed by veins of quartz, in places of epidote and calcite. This rock alternates with beds of purplish, reddish, or greenish slate or shale. The grit itself contains microscopical grains of quartz, orthoclase, plagioclase, and microcline feldspar, biotite, garnet, tourmaline, zircon, magnetite, ilmenite, and epidote, in a cement of chlorite, muscovite, quartz, calcite, epidote, and pyrite. In some places the grit contains beds of conglomerate up to 4 feet in thickness, with pebbles of quartz, orthoclase, plagioclase, microcline, granitoid gneiss or granite (with the same feldspars), fine-grained gneiss, and rarely chloritized diabase or gabbro, together with pebbles of the following sedimentary rocks: Quartzite (white, black, or red), greenish phyllite, siliceous shale and fine grit (carbonaceous, and sometimes calcareous, with angular grains of quartz, plagioclase, microcline, and scales of muscovite), granular

[a] See pp. 306-310 and Pl. C of paper No. 9, p. 11.

and crystalline limestone, and cryptocrystalline quartz (with grains of plagioclase, muscovite scales, rutile, calcite, and quartz veins). The diameter of these pebbles does not usually exceed an inch, but the quartzite sometimes attains 2 inches, the limestone 4, and the gneiss in one case measured 12 by 8 by 3.[a] Pl. II, *E* (p. 20), shows a microscopical drawing of the typical Rensselaer grit, and illustrates particularly the difference between its cement and that of the Hudson grit.

In the outlier, which extends from East Nassau to Old Chatham, the matrix of the grit is sometimes reddish, and where greenish the rock approaches a quartzite. Although the massive Cambrian quartzites (horizons B, D) are generally greenish and sometimes pass into conglomerates, they can usually be distinguished from the Rensselaer grit by their cement being mostly quartz and their grains and pebbles entirely quartz, with the exception of an occasional one of feldspar or slate.

STRATIGRAPHY.

The total thickness of the grits on the plateau was estimated at about 1,400 feet, but it may be a little greater. The portion of the plateau described in this paper consists of minor folds with a north or north-northeast trend. Some of these folds are exposed in the gorge of the Poesten Kill, between Barberville and a point a mile east of the village of Poestenkill.[b] Several folds are also crossed on the road leading northeast from Sandlake.

The outlier south of North Nassau consists of two masses, which at the north are separated by a swampy interval. Each of these consists of a syncline followed on the east by an anticline, but the entire outlier is probably made up of three anticlines and four synclines in alternation. (See Pl. III, Sec. *C*, p. 46.) The north end of the outlier west of East Nassau is a syncline.

The Rensselaer grit south of Alps village in Nassau strikes N. 70° E. and dips 50° to 60° NW. From this point the strikes in the adjacent Cambrian gradually curve southward for over 2 miles and in the outlier south of North Nassau resume their normal direction.

AREAL AND STRUCTURAL RELATIONS.

The relations of the Rensselaer grit are peculiar. Along the greater part of its western boundary it is bounded and underlain by the Lower Cambrian, and these relations reappear in the greater part of the large outlier in Nassau and Chatham and in the smaller one near North Nassau. In places, however, as near Tackawasick Pond (fig. 7), it overlies the Hudson (Trenton shale and limestone), and the outlier in Austerlitz lies upon the Hudson schist. Such relations signify: (1) That

[a] The dimension of 23 inches given on p. 308 of paper No. 9, p. 11, was an error.

[b] See figs. 34, 35, 36, and 37 on pp. 325-327 of paper No. 9, p. 11.

the Rensselaer grit is later than a part or the whole of the Hudson formation, and (2) that it was deposited in places upon a Lower Cambrian surface upon which the Hudson beds had never been deposited or from which they had been eroded.

That similar Lower Cambrian surfaces were above water during the deposition of the grit at no great distance is shown by the presence of quartzite pebbles within the grit. One of these conglomerate beds, with pebbles of quartzite an inch in diameter, occurs within a mile northeast of Tackawasick Pond, but the evidence from the pebbles shows that the grit was also unconformable to formations containing greenish phyllite, siliceous-carbonaceous shale or grit, crystalline limestone, and cryptocrystalline quartz. These may all have come from Lower Cambrian beds, but the black siliceous grit pebbles resemble the Hudson grit as much as they do the black pebbles of the Cambrian sandstone. In common with the Cambrian quartzite and the Hudson grit, the Rensselaer grit contains quartz, feldspar, and zircon fragments from the older crystallines. Its pebbles of granite and gneiss are still more conclusive on this point, and the large granite "pebble" shows that these older crystallines were not far distant.

Finally, two contacts along the western boundary of the grit will be described in detail. One of these is a half mile north of Hoag Corners, in Nassau, about 400 feet east of the road to Alps. A large outcrop of grit, striking N. 35° W. and dipping 40° E., is underlain by red and green shale, without small quartzite beds, and probably also belonging to the Rensselaer grit formation. About 150 feet west of the shale is the typical red shale of the Cambrian, with small quartzites, striking N. 15° E. and dipping 90°. This interval of 150 feet without outcrop may be occupied either by the Trenton limestone and shale, as it is 1¾ miles south (fig. 7, p. 21), or by the Cambrian shale. (See Pl. III, Sec. *C*, p. 46.)

The other, 11 miles north-northwest of the first, is in the town of Brunswick, where the road from Eagle Mills (Millville) toward Davitt Pond crosses the geological boundary. This contact is 3 miles east-southeast of Millville, where the road bends from a south-southeast to an east-northeast course. There are large outcrops of the red and green shale with small quartzites, with trails, etc., typical of the Lower Cambrian horizons A, C, E. At the road bend this shale dips 45°-70° E., and measures over 100 feet along the road, which crosses it diagonally. In contact with it on the east is a series of alternating small beds of reddish and greenish shale and fine-grained grit or quartzite of uncertain position. On the east side of, and in contact with, this series is a bed of typical Rensselaer grit 3 feet thick, with large pebbles of quartz, etc., dipping 90°, and followed by the usual alternations of shale and grit. The following measurements of this series of small

beds, intervening between the typical Rensselaer grit beds and the typical Lower Cambrian beds, were taken, and thin sections were prepared of beds marked 1 to 7, in order to determine how nearly the Rensselaer grit approaches the Lower Cambrian. The names attached to these beds are based upon these microscopical determinations.

Measured section at contact of Rensselaer grit and Lower Cambrian in Brunswick, 3 miles east-southeast of Eagle Mills.

Thin section.	Description of strata.	Thickness. Feet.	in.
	Rensselaer grit and interbedded shale or slate	Indef.	
7	Rensselaer grit, coarse, with pebbles of quartz and feldspar	4	6
6	Rensselaer grit, coarse and fine, in small beds	3	4
	Covered space, probably greenish shale	7	6
5	Rensselaer grit	2	
	Green shale with small gritty beds	8	4
	Rensselaer grit	1	
4	Red and green shale and small beds of Rensselaer grit	3	6
3	Bed of roundish quartz grains in a cement of chlorite with some secondary quartz	1	2
	Green shale with two small quartzose beds	3	4
2	Bed of angular quartz and plagioclase grains in a cement of chlorite	0	3-4
	Red and green shale	3	6
1	Rensselaer grit, thin bedded, with some shale	5	0
	Red shale with small quartzite beds, with trails, etc., typical of horizons A, C, E, of Lower Cambrian	50	0

This piece of investigation thus shows that the Rensselaer grit, the basal part of the Silurian, lies at this point immediately upon the red shale series classed as Lower Cambrian.

Finally, attention should be called to the significance of the position of the three outliers with reference to the plateau. The northern one is opposite the eastward recession of the edge of the plateau, and the western sides of both larger outliers are in about the same longitude as the most westerly part of the plateau in Poestenkill. This indicates that the southern prolongation of the plateau once extended at least that far west, while the third outlier in Austerlitz shows that the Rensselaer grit extended at least 7 miles south-southeast of the second outlier, or 12 miles south of the plateau itself. On the west side of the first road east of Tackawasick Pond, in Nassau, there appears to be still another outlier of Rensselaer grit, but it is too small to enter upon the map.

RÉSUMÉ OF THE FORMATIONS.

In the following table all the stratigraphical results from the study of the four formations are brought together and generalized. This table differs in important respects from that on pages 332, 333 of paper No. 9, p. 11, in which the Hudson shale and the Berkshire schist were unintentionally represented as not equivalent, and in which the relations of the Rensselaer grit to the Cambrian west of the plateau were not given at all.

Tabular résumé of the formations.

Period.	Formation.	Equivalent.	General description.	Thickness in feet.
Silurian.	Rensselaer grit. (In places rests uncomformably on Lower Cambrian.)	Oneida and Medina.	Dark-green metamorphic grit with interbedded reddish and greenish shale or slate and conglomerate, containing pebbles of quartzite, marble, black siliceous shale, grit, phyllite, all of Lower Cambrian age, some of them possibly of Ordovician age; also pebbles of gneiss and granite of pre-Cambrian origin.	1,400
Ordovician.	Hudson shale or Hudson schist. (Unconformity. Chazy absent, and lowest Trenton?)	Trenton.	Black, gray, greenish, and reddish shale, the black with Normans Kill graptolite fauna, and like the gray, interbedded with grit; black siliceous shale, one or several beds of limestone conglomerate, the pebbles of which carry Trenton, Chazy, and Lower Cambrian fossils. The gray shale in places with limestone having fossils of Trenton age. In the corresponding metamorphic zone sericite-schist with occasional thick beds of quartzite.	1,000–2,000+
	Beekmantown (Calciferous). (Unconformity. Upper and Middle Cambrian absent.)	Part of Stockbridge limestone.	Greenish-gray shale, with small beds of finely banded quartzite, sometimes calcareous and micaceous, carrying "*Levis graptolites*" and *Dictyonema* and *Clonograptus*.	50+
Cambrian.	Lower Cambrian.	Part of Stockbridge limestone, Greenwich slate of Washington Co., N. Y., Vermont formation of Massachusetts and Vermont.	Alternating beds of limestone, black or gray shale, calcareous sandstone; the limestone often brecciated and in places a conglomerate, all with *Olenellus* fauna. The above underlain by reddish and greenish shale with *Oldhamia* and *Hyolithes*, and these in places by an olive grit or a sandstone passing into quartzite. The lowest beds exposed are reddish and greenish shale with thin quartzite beds, carrying *Oldhamia*, etc., interbedded with two beds of greenish quartzite, each 8 to 50 feet thick.	1,225+

STRUCTURAL GEOLOGY.

STRUCTURE SECTIONS.

Section *A*, Pl. III, shows the unconformable relations between the large synclinal outlier of Hudson shale and the Lower Cambrian; also that between the Silurian Rensselaer grit and the Lower Cambrian, as well as the overthrust at the west which has brought the Lower Cambrian on to the Hudson. The section involves three periods of folding, one at the close of the Lower Cambrian, another at the close of the Ordovician, and still another which metamorphosed and folded the Silurian beds. That these last two movements were not identical, i. e., that the Ordovician beds were folded before the Silurian beds, is shown by the well-known unconformable relations between the Ordovician and the Silurian at a number of points in the Hudson Valley.[a]

As the Silurian movement in New York seems to have been confined to an emergence causing a slight retreat of the shore line, and as both Silurian and Devonian beds in conformable relations are powerfully folded at Becraft Mountain, scarcely 25 miles southwest of the Rensselaer Plateau,[b] the movement which affected the Silurian grit of Rensselaer County does not date further back than the close of Devonian time, and may have occurred as late as the close of the Carboniferous.

Section *B*, Pl. III, crossing the smaller synclinal outlier of Hudson, repeats essentially the features of Section *A*. In both it is assumed that the unconformity between the Beekmantown and the Trenton represents merely an emergence followed by a period of denudation. In both sections the minor folds in the broad Cambrian area are necessarily largely hypothetical.

Section *C*, Pl. III, shows mainly the general structure of the small outlier of Silurian resting upon the Cambrian.

GENERAL STRUCTURE.

The general structural features are: The westwardly overturned folds which mark a large part of the area; the presence of an anticline of this character, the rupture of which resulted here and there in an overthrust at the west; east of this a synclinal axis running through both of the Ordovician outliers, with a complex anticline east of it. The most important inference, however, to be drawn from the sections is the presence of three periods of folding: The Lower Cambrian one, which raised some parts of the Cambrian area above water; that at the

[a] See Davis, William M., The nonconformity at Rondout, N. Y.: Am. Jour. Sci., 3d ser., vol. 26, 1883, p. 389. Van Ingen, Gilbert, and Clark, P. Edwin, Disturbed fossiliferous rocks in the vicinity of Rondout, N. Y.: Report New York State Paleontologist for 1902, 1903, p. 1176. Darton, N. H., Preliminary report on the geology of Ulster County, N. Y.: Rept. State Geologist of New York for 1893, p. 357.

[b] See Grabau, Amadeus W., Stratigraphy of Becraft Mountain, Columbia County, N. Y.: Rept. New York State Paleontologist for 1902, 1903, p. 1030.

PLATE III.

PLATE III.

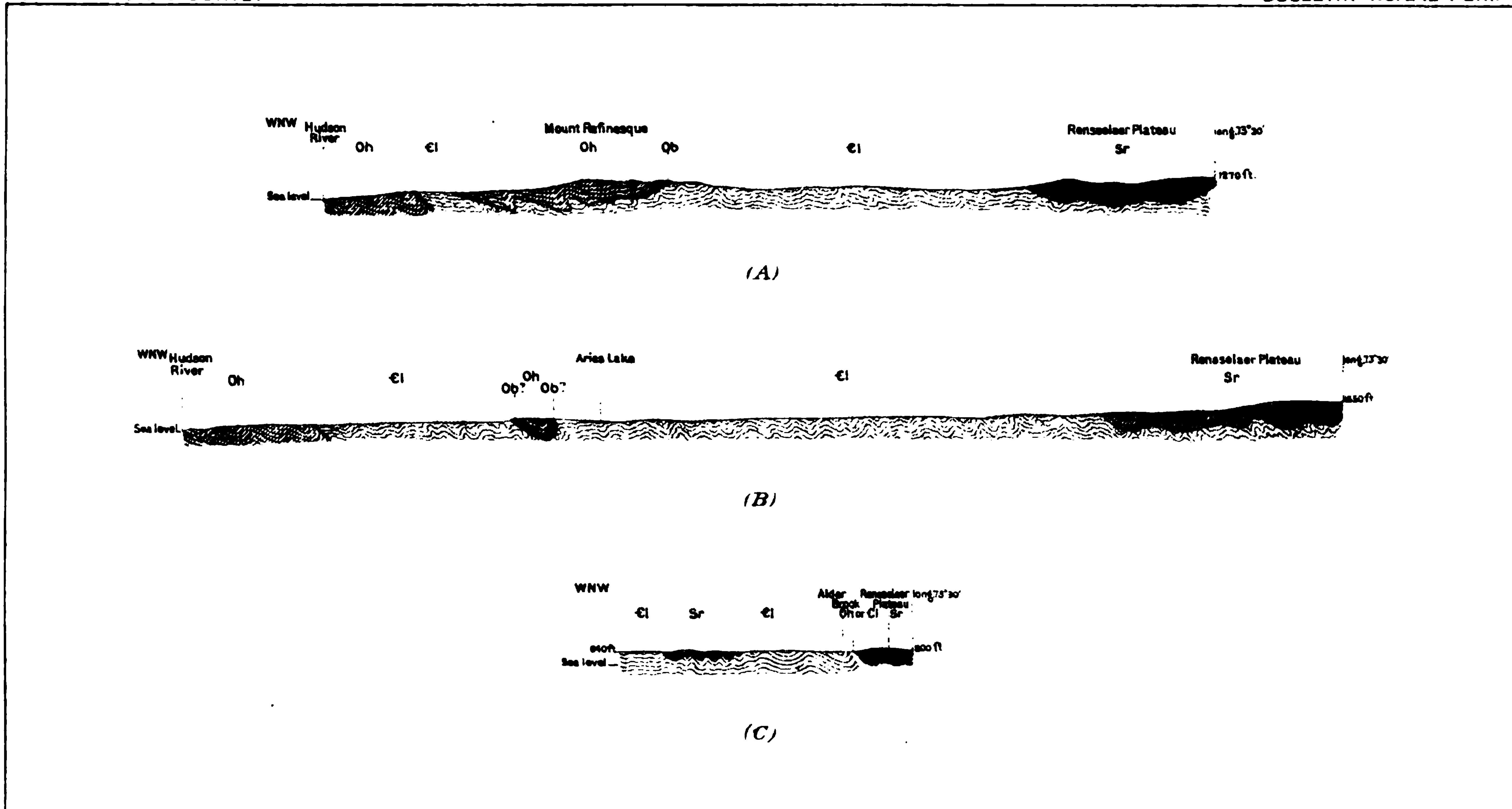
STRUCTURE SECTIONS.

A. Section from near Quackenkill, in Grafton, to the Hudson 2 miles north of Lansingburg.

B. Section from a point 2 miles east of Sandlake to the Hudson 2 miles south of South Troy.

C. Section in Nassau from the western edge of the Rensselaer Plateau to a point a mile south-southeast of Burden Lake.

In these sections Ꞓl=Lower Cambrian; Ob=Ordovician, Beekmantown; Oh=Ordovician, Hudson; Sr=Silurian, Rensselaer grit. Scale, one-half inch=1 mile.



SECTIONS ALONG THE LINES A, B, AND C, PLATE I

JULIUS BIEN & CO LITH. N.Y.

close of the Ordovician, which not only folded the Hudson and the Beekmantown beds, but also modified and faulted the Lower Cambrian folds; and one at the close of Devonian or Carboniferous time, which folded and metamorphosed the Silurian grit, and which must also have modified both the Ordovician and the Cambrian folds. The sections also imply the existence, in places, of a Lower Cambrian land surface in Ordovician time, which became partially submerged in Silurian time.

DISCUSSION AND CONCLUSIONS.

The paleontological, petrographical, and stratigraphical observations, given in detail, and summarized in the table and the sections, speak for themselves. It remains but to discuss some of their general bearings and to draw a few brief conclusions. This will be done under separate topics.

THREE CRUSTAL MOVEMENTS.

The evidence of the crustal movement (1) at the close of the Lower Cambrian along the western side of the Taconic Range is not confined to the unconformable areal relations of the Lower Cambrian and Ordovician in Columbia, Rensselaer, and Washington counties,[a] nor to the pebbles containing Lower Cambrian fossils found by Ruedemann in conglomerates of Hudson (Trenton) age and partially confirmed by the occurrence of grains of clastic rocks in the Hudson grit, but is made conclusive by the structural unconformity of the two formations recently observed at the north end of the Taconic Range in Rutland County, Vt.[b]

The Taconic or Green Mountain movement (2), which folded the Ordovician beds at Rondout and other places in Ulster County, and also in Orange County,[c] where the Silurian beds lie on their eroded edges, also folded and faulted the Hudson shale of this part of the Hudson Valley, and folded and metamorphosed the Hudson beds of the Taconic Range.

To the post-Devonian or Carboniferous movement (3), which folded both Devonian and Silurian beds at Becraft Mountain, in Columbia County, must be assigned the folding and the metamorphism of the Silurian grit of the Rensselaer Plateau. A similar movement metamorphosed Devonian fossiliferous beds at Bernardston, Mass., on the west side of the Connecticut Valley, about 50 miles east of the west edge of the Rensselaer grit deposit;[d] and that movement may possibly

[a] For Washington County see Pl. XIII and pp. 290, 291 of paper No. 13, p. 11.

[b] See Dale, T. Nelson, The geology of the north end of the Taconic Range: Am. Jour. Sci. 4th ser., vol. 17, Mar. 1904, p. 185, and map, Pl. XI.

[c] See Ries, Heinrich, Geology of Orange County: Fifteenth Ann. Rept. State Geologist of New York, 1895, Pl. XX.

[d] See Emerson, Benjamin K., Geology of old Hampshire County, Mass., comprising Franklin, Hampshire, and Hampden counties; Chapter IX, The Bernardston series of upper Devonian rocks, and Pl. IV: Mon. U. S. Geol. Survey, vol. 29, 1898.

have extended across the Green Mountain crystalline axis and the Taconic synclinorium to the Rensselaer Plateau. Traces of a secondary crustal movement have been found here and there in the schist of the Taconic Range in the form of secondary cleavage foliations, sometimes plicated or followed by the formation of fresh sericite.[a]

THREE CONGLOMERATES.

The lowest of these occurs within the Lower Cambrian beds, and implies a temporary emergence sufficient to expose the beds to wave action and thus to form beach pebbles. The next consists of limestone pebbles within the Hudson shale. It implies a temporary emergence during Ordovician time; and the paleontological evidence obtained by Ford and Ruedemann from the pebbles shows that Lower Cambrian, Chazy, and Trenton rocks were above water during that part of Trenton time. Whether these Trenton pebbles came from a distance or from limestone beds formed in situ and then exposed to wave action, as in the case of the Lower Cambrian conglomerates, may be difficult to determine.

The third conglomerate is that of the Rensselaer grit, formed in Silurian (Upper) time. Its pebbles show that Cambrian quartzites were then above water at no very great distance; that slate, carbonaceous shale and grit, and marble, of Cambrian or Ordovician age, were likewise above water; also that detritus from coarse granites and fine gneisses was being brought into the sea near by. The distance of the plateau from the crystallines at the northwest (about 25 miles)[b] and at the east (11 miles), and the large size of one of the granite pebbles (12 by 8 by 3 inches), raise a difficulty here. Mr. G. K. Gilbert's suggestion that there may have been a pre-Cambrian mass in the center of the plateau that supplied these pebbles, which became concealed by the later beds of the grit or by drift or swamp, is valuable. Such a pre-Cambrian mass occurs at Stissing Mountain, 40 miles south-southeast of the Rensselaer Plateau and about 15 miles west of the Green Mountain crystallines. Furthermore, the presence of such a crystalline core in the plateau would help to account for the metamorphism of the grits, as the crystalline core of the Green Mountain axis accounts, in part, for the metamorphism of the Paleozoic sediments on either side of it. Such a core would furnish a buttress against which the grits have been pressed and thus metamorphosed.

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[a] See Mon. U. S. Geol. Survey, vol. 23, p. 143, Case IV; p. 151, Case VIII; also pp. 321-324 of paper No. 9, p. 11 of this bulletin; p. 564, fig. 566, of paper No. 12, p. 11 of this bulletin.

[b] See Merrill, Frederick J. H., Geological Map of New York, Exhibiting the Structure of the State as far as Known, 1901.

MINOR OSCILLATIONS.

Thus, in addition to the three main crustal movements, the Cambrian and Ordovician conglomerates indicate a minor oscillation in Lower Cambrian time and another in Trenton time. There was also an emergence at the close of Beekmantown time, for the Hudson lies in places immediately upon the Beekmantown, the Chazy being absent. The full thickness of this formation in the Lake Champlain region is estimated at 890 feet.[a] Mr. Ruedemann's doubtful determination of Chazy graptolites in a 40-foot outcrop at the Deep Kill can not suffice to substantiate the presence of a formation representing such a lapse of time as is implied in the deposition of 890 feet of limestone.

The writer in 1901 found in the town of Shoreham, in Addison County, Vt., a small anticlinal hill of Potsdam overlain by the Trenton-Utica, the Beekmantown and Chazy being absent. Such minor oscillations seem to have marked the entire Hudson-Champlain region during Paleozoic time.

ABSENT FORMATIONS.

The formation which, owing to unconformity, is not at all represented within this area, is the Middle Cambrian. The Upper Cambrian and the Chazy are also practically absent, besides possibly the lowest Trenton. Of these the Upper Cambrian, or Potsdam proper, occurs around the southern border of the Adirondack mass, 25 miles north-northwest of Troy, and the Chazy about the same distance in north-northeast and north-northwest directions, and probably also forms part of the Stockbridge limestone, 20 miles northeast and southeast of Troy. The significance of the absence of these formations is that the Lower Cambrian was here a land surface at least during Middle Cambrian time, and that the Beekmantown was also a land surface during Chazy time, and may possibly have remained so during very early Trenton time.

The absence of the Middle Cambrian fauna agrees with the structural evidence of movement, which involved the Lower Cambrian beds, in pointing to the existence of a land surface here during Middle Cambrian time. But the absence of exclusively Upper Cambrian fossils, as well as the mingling of the equivocal *Dictyonema* with Beekmantown graptolites, indicates the submergence of the Middle Cambrian land surface in Beekmantown time and the consequent immigration of Beekmantown graptolites along with the *Dictyonema* which may have survived from the Upper Cambrian. Messrs. Walcott and Schuchert, to

[a] See Brainard, Ezra, The Chazy formation in the Champlain Valley: Bull. Geol. Soc. America, vol. 2, 1891, p. 293.

whom this question has been submitted, agree in the opinion "that the data at hand are not clearly sufficient to determine whether or not the mingling of the *Dictyonema* with the Beekmantown graptolites indicates the continuance of Middle Cambrian land into the later portion of the Upper Cambrian time."

EQUIVALENT FORMATIONS.

The entire Lower Cambrian series, shown in the tables on pages 29 and 43, is regarded as the offshore but shallow-water equivalent of the Lower Cambrian conglomerate, quartzite, schist, and dolomite which border the Green Mountain pre-Cambrian axis (Vermont formation and basal part of Stockbridge limestone of Monograph XXIII). It is assumed that sediments of Lower Cambrian age forming the base of the Taconic synclinorium are continuous from Hoosac Mountain to Troy, with a possible interruption by an island of pre-Cambrian within the area of the Rensselaer Plateau, but that the character of these sediments changes with the distance from the highlands of pre-Cambrian time and with the westward decrease of metamorphism. The Lower Cambrian series is also regarded as equivalent to the Greenwich formation of Washington County, N. Y., and Rutland County, Vt., where, however, the moderate metamorphism and the regularity of the compression which attended the crustal movement at the close of the Lower Cambrian changed the shale into slate, and where also the basal part of the formation as exposed in Rensselaer County (horizons A to E of table on p. 29) does not appear to be exposed.[a]

The Beekmantown of the Hudson Valley is regarded as the equivalent of the Beekmantown part of the Stockbridge limestone. That formation represents the upper part of the Lower Cambrian, the Beekmantown, the Chazy, and the lower part of the Trenton. The Stockbridge limestone usually disappears from east to west under the Hudson schist of the Taconic Range, owing, it is now thought, to the presence of a Lower Cambrian shore line there and to the overlapping of that limestone along that shore line by the Hudson schist (Berkshire schist) during a submergence which took place in Trenton time.[b] As the fossiliferous Trenton limestone along the west edge of the plateau in Nassau is associated with shale, it probably belongs to the Hudson formation and not to the Stockbridge limestone. For these reasons the Beekmantown shale of the Hudson Valley, although equivalent to the Beekmantown part of the Stockbridge limestone, is regarded as belonging to different basins which were separated by an island (?) of Lower Cambrian.

The Rensselaer grit is regarded as the equivalent of the Oneida and

[a] See table opposite p. 178 of paper No. 13, p. 11.
[b] See op. cit. on north end of Taconic Range.

the Medina. Its estimated thickness of 1,400 feet compares fairly well with the estimates for these formations in western New York of 1,158 feet,[a] and in Pennsylvania of 1,125 feet.[b]

DENUDATIONS.

One of the marked features of the region is the repeated denudation which it has undergone. Passing by the denudation which accompanied the minor emergence that produced the Cambrian conglomerate, the first important denudation began in Lower Cambrian time and continued during Middle and Upper Cambrian. Upon the eroded Lower Cambrian surface the Beekmantown and Hudson shales were deposited. But as both the Hudson (Trenton) grit and the Rensselaer grit (Oneida-Medina) contain pebbles of Lower Cambrian age, denudation of a portion of the Cambrian surface must have gone on in Ordovician and early Silurian time. Omitting the denudation which accompanied the minor emergence implied in the Ordovician conglomerate, there is the unconformity between the Beekmantown and the Trenton, representing a time interval sufficient for the deposition of 890 feet of limestone in the Champlain region, during which much denudation must have taken place. It is uncertain, however, whether the absence of the Beekmantown shale from so large an area of Lower Cambrian is to be attributed to the denudation of Chazy time or to a later one. The next important denudation followed the Green Mountain movement and affected the Hudson shale and schist. As the Hudson shale (e. g., at Rondout and Becraft Mountain) was eroded before the deposition of the Silurian, it follows that the transition from the Ordovician to the Silurian was not simply attended by a retreat of the sea consequent upon the folding and elevation of the Ordovician beds, but that after these folded beds had been eroded there occurred a sufficient submergence to bring the sea back again over the denuded Ordovician surfaces east of the Hudson, at least as far as the eastern edge of the Rensselaer Plateau.

As the Rensselaer Plateau lies in some places upon Hudson beds and in others upon Lower Cambrian beds, it is evident that where it overlies the Lower Cambrian that surface had either been denuded of its Ordovician beds or else formed part of the Cambrian surface which had remained above water during Ordovician time and which became submerged in the Silurian transgression. It may not be possible to determine which of these two possibilities is a probability.

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[a] Prosser, Charles S., The thickness of the Devonian and Silurian rocks of central New York: Bull Geol. Soc. America, vol. 4, p. 117.

[b] Lesley, J. P., Second Geol. Survey of Pennsylvania, Final Report.

But there was also a third denudation, which began at the close of the Oneida and Medina and which eventually severed the Rensselaer Plateau from the outlying masses in Nassau, Chatham, and Austerlitz. The two outliers of Hudson, lying in the same synclinal axis, must have once been continuous. It is a question whether the denudation which removed the intervening mass of Hudson shale and thus reexposed the old Cambrian land surface was that which occurred between the Ordovician crustal movement and the Silurian transgression, or whether the post-Silurian denudation did the major part of the work. In this case, as the time interval since the post-Devonian or Carboniferous crustal movement was so much greater, it seems probable that the work was done mostly during the third period of denudation, although at the beginning of that period a certain thickness of Silurian would have to be removed before the partially eroded Ordovician surface could have again been reached.

EXTENT OF THE LOWER CAMBRIAN LAND SURFACE.

The Lower Cambrian land surface was bounded on the north and northwest by the sea which formed the Upper Cambrian (Potsdam) deposits about the Adirondack mass and on the east side of Lake Champlain, but the data require a Lower Cambrian land surface during Ordovician time not very distant from the conglomerate bed at Rysedorph Hill, nor from the Hudson grit in general. Such a surface would have to lie east of the axis of the two outliers. If the Cambrian area in Pittstown and Brunswick be followed around the northern end of the plateau it will be found to connect with one which terminates near the village of Cambridge in Washington County.[a] There appears to be a continuous Lower Cambrian surface at least from the Columbia County line to Cambridge, a distance of about 35 miles, and in width from 2 to 4 miles, which is the distance between the plateau and the Hudson outliers or masses on the west. As the northwestern part of the Rensselaer Plateau lies on the Lower Cambrian it is possible that the area west of a line running north-northwest from North Nassau under the plateau to Potter Hill, in the town of Hoosic, may have, in Ordovician time, formed part of the Cambrian land surface. In that case the width of that surface would have been 2 to 3 miles greater. But the data also require a Cambrian land surface during Silurian time on the landward side of the Rensselaer grit. As the Silurian transgression presumably came from the southwest, this Cambrian area would have to lie north of the plateau, and it would also have to be south of Cambridge. It would thus form the northern part of the area just outlined.

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[a] See map, Pl. XIII, of paper No. 13, p. 11.

EXTENT OF THE BASAL SILURIAN BEDS.

The Rensselaer grit of the plateau and its three outliers must needs have been originally connected and also continuous with other Silurian deposits. The geographical relations of the Rensselaer grit to the Silurian formations west of the Hudson River are shown on the Lower Hudson, the Hudson-Mohawk, and the Central sheets of Merrill's geological map of New York.[a] It will be noticed that the northern edge of the Rensselear Plateau is in nearly the same latitude as the boundary between the Silurian (Oneida-Medina) and the Ordovician (Hudson) in Herkimer County, and that its southern part is in line with the southern continuation of the same boundary along the Kittatinny Mountain. The plateau thus lies at the apex of the angle formed by the receding shore line of Silurian and Devonian time, as indicated by the outcrops. The west-northwest and east-northeast strikes at the north end of the plateau and the east-northeast one in the Hudson shale on Mount Rafinesque are either related to the general movement which resulted in the general east-west course of the boundary between the Ordovician and the Silurian across the State of New York or else are due to transverse folding. For all these reasons it may be assumed that the grit mass now forming the plateau was near the end of the Silurian bay; but in the Taconic Range, in the northern half of Rutland County, Vt., about 57 miles north-northeast of the northern edge of the plateau, lies another mass of grit and conglomerate, also containing pebbles of Cambrian quartzite and also overlying the Hudson schist, but only about 500 feet in thickness, and covering not quite 4 square miles.[b] The bay of Silurian time may thus possibly have sent an arm up the Champlain Valley.

HISTORICAL GEOLOGY.

With the aid of these conclusions the main outlines of the geological history of this portion of the Hudson Valley may be tentatively drawn. As the presence of a core of pre-Cambrian granite and gneiss within the Rensselaer Plateau area is not yet established, geological history does not begin here until after the Cambrian transgression, and it begins with the presence of the Lower Cambrian sea, with its fauna chiefly of trilobites, brachiopods and pteropods, and a flora abounding in *Oldhamia*, if it be a plant. The sediments were alternately sandy, clayey, and calcareous-organic. The sea was shallow and there was one slight emergence of short duration during a general gradual subsidence. At the close of Lower Cambrian time a crustal movement folded these sediments, and the sea retreated northward, northwestward, and possibly in other directions. The new land surface became

[a] Op. cit.

[b] See paper No. 14, p. 11.

exposed to atmospheric erosion during Middle and Upper Cambrian time. Toward the close of Upper Cambrian time, at least the western part of this Cambrian land surface became submerged and the Beekmantown graptolites, together with some surviving Upper Cambrian forms, appeared. This submergence was of relatively short duration, and an emergence took place during Chazy time which may have lasted into early Trenton time, when another submergence occurred. Another great series of sandy, clayey, and calcareous sediments was then deposited, also upon a shallow subsiding sea floor. An abundant graptolite fauna (Normans Kill) flourished, and at intervals a Trenton fauna of tetracorallia, crinoids, gastropods, polyzoa, brachiopods, trilobites, etc.[a] One or more brief emergences and submergences occurred in places during this time, resulting in the formation of conglomerates, the pebbles of which show that limestone rocks of Lower Cambrian, Chazy, and Trenton age were above water at no great distance.

At the close of Ordovician time the powerful crustal movement which formed the Taconic Range folded the Trenton and Beekmantown sediments and with them refolded and faulted the Lower Cambrian sea bottom. The metamorphism attending this movement extended to the western foot of the Taconic Range. The sea retreated southward and westward. A period of denudation set in which affected the Ordovician beds and still further eroded the Lower Cambrian areas (islands?), which had remained unsubmerged during Ordovician time. Then came the Silurian transgression, which again submerged the Ordovician areas and part of the still exposed Lower Cambian area. The Silurian sea formed a bay, the wider part of which seems to have terminated in the region of the Rensselaer Plateau. The sediments deposited at this time were alternately clayey and sandy, with occasional pebbly beds, the pebbles of which came from pre-Cambrian coarse granites and fine gneisses above water at no great distance, and also from Lower Cambrian quartzites and from slate, shale, grit, and marble of Lower Cambrian or Ordovician age. The land areas from which the Cambrian pebbles came were probably north of the plateau.

These Silurian beds may have become exposed to denudation soon after their deposition, owing to a slight emergence and the retreat of the shore line in the Silurian bay. However that may have been, at the close of Devonian or of Carboniferous time these beds were folded and somewhat metamorphosed, and this movement also affected the Ordovician sea bottom. The region has been greatly denuded since Devonian time, and this denudation was greatly facilitated by one or more uplifts and finally by glacial action. The extent of this denudation is shown by the outliers of Hudson shale and Rensselaer grit,

[a] See p. 101 of paper No. 16, p. 11.

and still more by the isolation of the three masses of Rensselaer grit from other Silurian deposits of the same age.

This region thus shows the effects of three transgressions (Lower Cambrian, Ordovician, and Silurian), three or more minor recessions and advances of the sea (one in Lower Cambrian and one or more in Trenton), of three crustal movements (Lower Cambrian, Ordovician, and Devonian or Carboniferous), and of four periods of denudation (at close of Lower Cambrian, of Beekmantown, of Trenton, and in post-Silurian time), besides those attending the minor recessions in Lower Cambrian and Trenton time. The history of this portion of the Hudson Valley was eventful indeed.

The facts presented will also be found to have some bearing upon the geographic-paleontological theories recently set forth by Messrs. Ulrich and Schuchert. (See paper No. 18, p. 11).

ECONOMIC GEOLOGY.

The rocks of this tract have thus far proved of little economic value. The Cambrian limestone breccia, when in beds of sufficient thickness, makes a good building stone of unique appearance. The Hudson grit is used for foundations. The carbonaceous-siliceous shales of the Hudson formation, quarried near Grandview Hill, are useful for country roads, and the shales of all the formations are serviceable for application to sandy roads. The red shales of the Lower Cambrian (horizons A, C, E, of table on p. 29), quarried west of Burden Lake, and of the Silurian Rensselaer grit have been used in the manufacture of putty and paint. The coarser beds of the Rensselaer grit, with their dark-green matrix and occasional white, reddish, and bluish pebbles, become a beautiful rock when polished[a] and would answer for indoor decoration. Efforts to utilize it for outdoor purposes have failed because of the small percentage of lime in the matrix, the surface of which, under continued expósure, thus acquires a spongy texture.

But the chief economic value of these formations lies in their relation to agriculture. The greenish shale of the Lower Cambrian (horizons C, E, H), which covers so many square miles of the valley, owing to its numerous planes of bedding, cleavage, and jointing, and to the action of rain, changes of temperature, and frost, breaks up into roughly quadrangular, stick-like fragments which gradually pass into a clayey subsoil and soil. Upon this, rye, which is one of the chief products of Rensselaer County, and is cultivated as much for its straw as for its grain, thrives. Specimens of soil and subsoil of this origin, from typical rye lands in this county, were submitted in 1894 to Prof. Milton Whitney, of the United States Department of Agriculture, for mechanical analysis. The results of the analyses are as follows:

[a] See Pl. C of paper No. 9, p. 11, for a colored lithograph of polished specimens.

Mechanical analysis of soils from Rensselaer County, N. Y.

	1721, soil.	1722, subsoil.
	Per cent.	*Per cent.*
Moisture in air-dry sample	2.48	2.02
Organic matter	8.17	6.42
Gravel (1-2 mm.)	7.03	7.71
Coarse sand (0.5-1 mm.)	4.66	4.33
Medium sand (0.25-0.5 mm.)	4.64	3.74
Fine sand (0.1-0.25 mm.)	3.93	3.59
Very fine sand (0.05-0.1 mm.)	19.47	19.00
Silt (0.01-0.05 mm.)	35.37	34.17
Fine silt (0.005-0.01 mm.)	6.51	8.21
Clay (0.0001-0.005 mm.)	8.58	10.60
Material larger than 2 mm	38.00	22.00
"Fine earth"	62.00	78.00
	100.00	100.00

Professor Whitney, in a letter to the writer, offered the following remark on these analyses:

I think it is not hard to point out the reason why this soil is considered poor and why it is not adapted to wheat and grass. If the soil were composed wholly of the fine earth and had none of the coarse material of the undecomposed shale, the soil itself would contain, according to our analysis, 8.53 per cent of clay and the subsoil 10.60 per cent. This would be much less than is necessary for a good wheat land, except in cases where there is a large amount (45 per cent or over) of silt. The samples would be considered too light in texture for wheat or grass and not sufficiently retentive of moisture. These have, however, about the same texture as good fruit land with us, especially adapted for peaches. When we consider, however, that this fine earth represents only about 62 per cent of the soil and 78 per cent of the subsoil, while the remaining 38 per cent in one case and 22 per cent in the other is coarse, inert material, it will be seen that the actual amount of clay in the soil is very much less than would be indicated by the mechanical analyses of the fine earth. Instead of there being 10 per cent of clay in the subsoil there would be very much less than this, and too little, I should say, to give the proper supply of water to the staple agricultural crops.

As a matter of observation, rye seems to have such an affinity for this Cambrian shale that the stalks will grow almost on a bare ledge of it. Under the microscope this shale is seen to consist largely of potash mica (see Pl. II, *B*), and as the ash of the grain contains 32.10 per cent and that of the straw 22.56 per cent of potash[a] there may be a slight chemical relationship between the supply of potash by the soil and its requirement by the plant, which, added to the permeability and other physical properties of the soil, makes it peculiarly favorable for the cultivation of rye.

The region also affords an illustration of the effect of the uneconomic use of geological and topographical conditions—i. e., of unwise defor-

[a] Strassburger, Noll, Schenck, and Schimper, Lehrbuch der Botanik, 2d ed., Jena, 1895, p. 147.

estation.[a] The Rensselaer Plateau is the natural source of water supply for towns along the east shore of the Hudson for a stretch of 20 miles, but it was deforested over a half century ago, with the effect of diminishing the quantity and lowering the quality of the supply.

SUBJECTS FOR FURTHER INVESTIGATION.

These geological studies indicate the directions in which further investigations are needed. These are:

(1) Very minute exploration of the Rensselaer Plateau area for a pre-Cambrian mass.

(2) The determination of the structure of the bed or beds of limestone conglomerate in the Moordener Kill, in order to ascertain whether there was more than one emergence in Hudson time.

(3) A careful search for Beekmantown graptolites in the areas mapped as Lower Cambrian, with a view to determining the exact areal extent and the thickness of the Beekmantown formation.

(4) Further search for fossils in the belt of shale with small quartzite beds which lies between Schaghticoke and Valley Falls and extends north to the Washington County line.

(5) Search for favorable points for the measurement of the Lower Cambrian shale horizons A, C, E, H, with a view to making a more nearly correct measurement of the thickness of the Lower Cambrian exposed.

(6) The extension of the areal and structural work, thus begun, into Columbia County to that point where the Ordovician areas on each side of the Cambrian meet, and also northward into Washington County.

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[a] See p. 299 of paper No. 9, and a quotation from Spafford in paper No. 21, in list on p. 11 of this bulletin.

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DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., May 11, 1904.

SIR: I have the honor to transmit herewith the manuscript of a report on the cement materials and industry of the United States, by Edwin C. Eckel, and to recommend its publication as a bulletin.

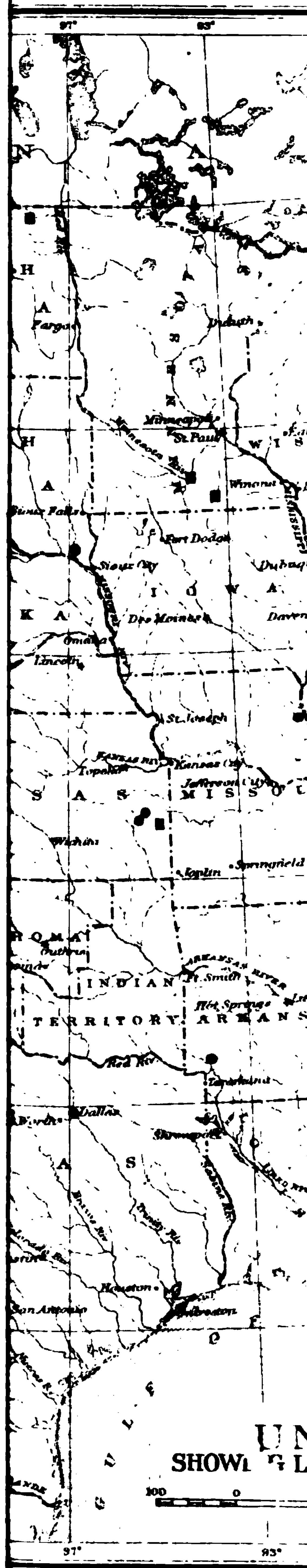
This report has been prepared in accordance with the policy of summarizing existing information concerning one or more of the nonmetalliferous mineral products each year. It contains, however, an exceptionally large proportion of entirely new information. In its preparation Mr. Eckel has visited every district in which cement was being produced and has examined nearly every plant in operation. Information relating to undeveloped deposits of cement materials has been obtained by personal examination and from the published and unpublished work of other geologists.

The object has been to treat the subject from the geological rather than the technical standpoint, although the technology of cement manufacture is also discussed with sufficient fullness for the purpose of the report. In view of the phenomenally rapid growth of the cement industry within recent years, the publication of this report will be exceptionally timely,

Very respectfully,

C. W. HAYES,
Geologist in Charge of Geology.

Hon. CHARLES D. WALCOTT,
Director U. S. Geological Survey.



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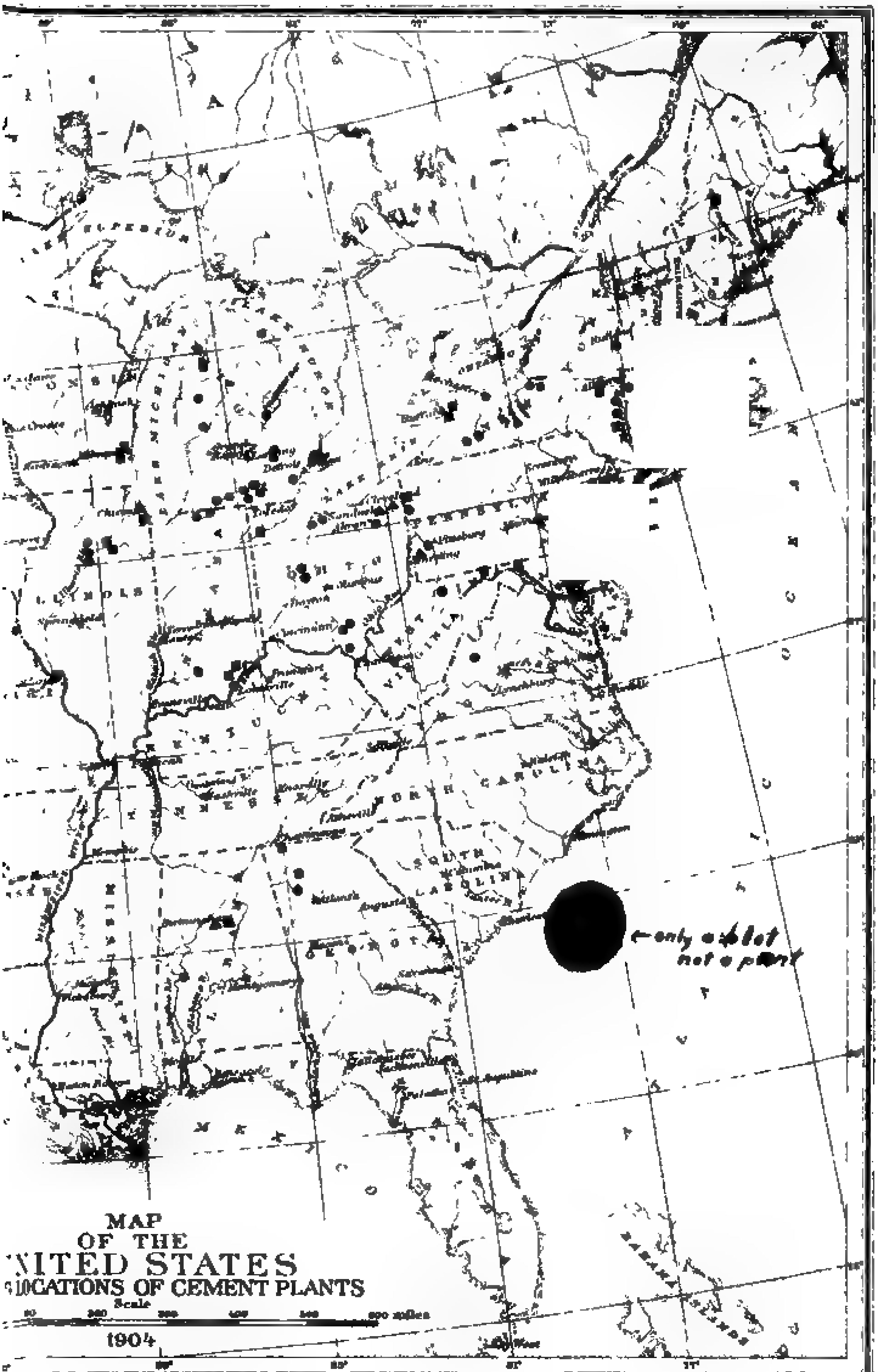
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LOCATIONS OF CEMENT PLANTS
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1904

CEMENT MATERIALS AND INDUSTRY OF THE UNITED STATES.

By Edwin C. Eckel.

INTRODUCTION.

The marvelous growth of the American Portland-cement industry during the last decade has created a widespread interest in the raw materials and in the methods of manufacture of Portland cement—the most important of the cementing materials. This interest is not confined to those who have a direct financial stake in the industry, as the product is so widely used, and its uses are so rapidly increasing, that some knowledge of its manufacture and properties is of advantage to everyone connected, directly or indirectly, with engineering or building operations. In its importance to our present civilization cement is surpassed among mineral products only by iron, coal, and oil; in rate of increase in annual production during the last decade even these three products can not be compared with it. In 1890 the total production of Portland cement in the United States was 335,500 barrels, valued at $439,050; in 1903 it exceeded 22,000 000 barrels, while the value was over $27,000,000.

The rate of growth of the industry is shown graphically by fig. 1. The value of the annual production of Portland cement in the United States has been plotted on this diagram for the sixteen years 1888–1903, inclusive. During the sixteen years which witnessed the development of the American Portland-cement industry two of the greatest gold discoveries in the world's history were made—in Colorado and Alaska. The annual gold production of Alaska and of the Cripple Creek district in Colorado have been accordingly placed on the diagram. These two great gold strikes impressed themselves on every citizen of the United States, while the Portland-cement industry has attained its growth in comparative obscurity. Yet on comparison it will be seen that the gold production of Cripple Creek is only slightly greater than the output of Portland cement, while the production of Alaska sinks into comparative insignificance. On examining the diagram it will be seen, moreover, that the greater part of this

increase has been within the last decade. The production of Portland cement has risen from a little less than $2,500,000 in 1896 to over $27,000,000 in 1903.

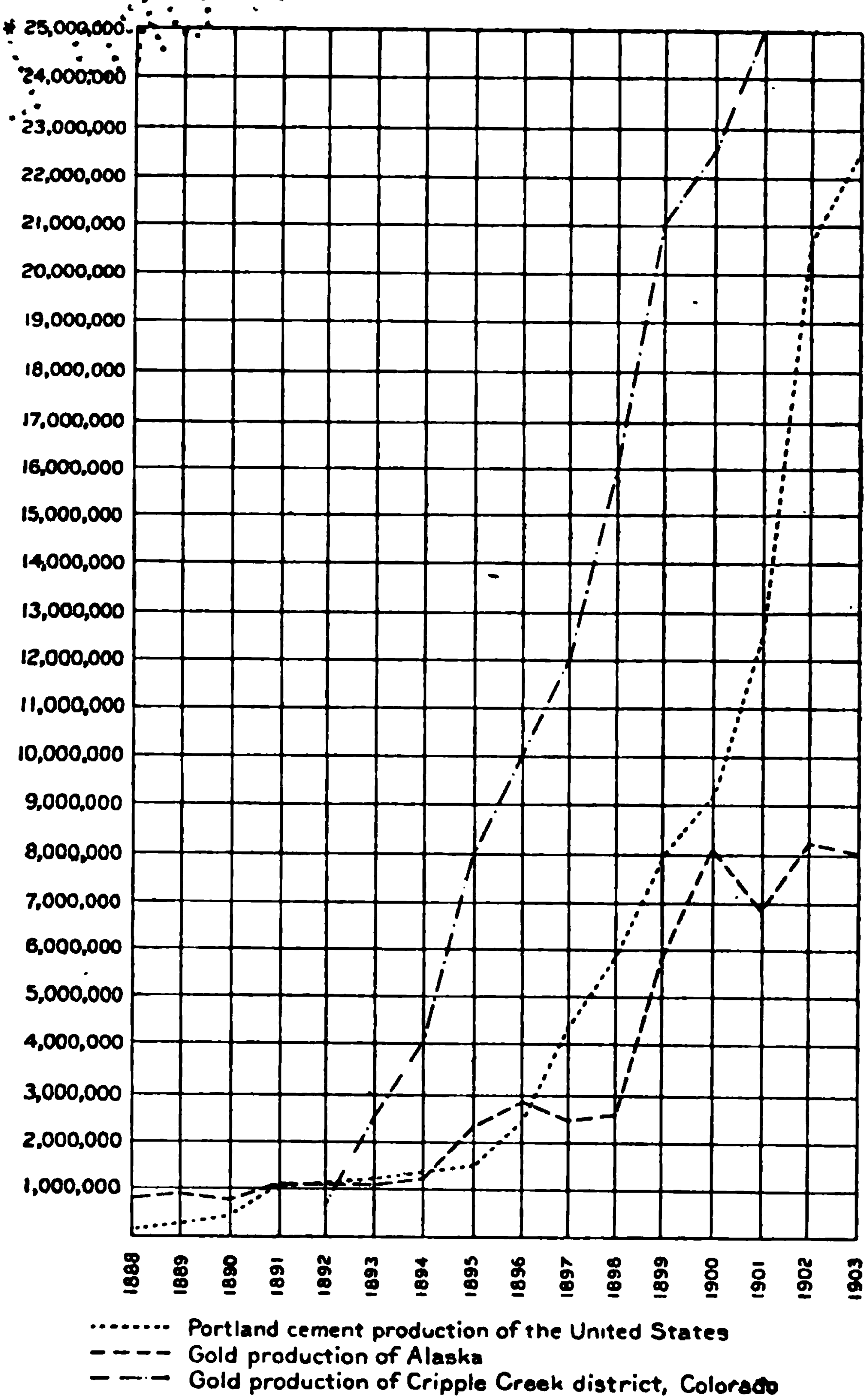

FIG. 1.—Portland cement production of the United States, 1888-1903.

This report has been prepared in order to give information on cement materials, which is desired by two classes of persons. First, owners of lands on which marl, limestone, or clay deposits are found often inquire whether a given material is suitable for Portland-cement manufacture. In response to such questions the writer has attempted,

in the preliminary chapters, to describe the chemical and physical properties which a Portland-cement material must have, and also to show that the value of cement material depends almost entirely upon location with respect to fuel supply, transportation routes, and markets. Second, cement manufacturers or those wishing to engage in the cement industry often inquire concerning the localities in some given State or group of States where cement materials will probably be found and desire information in advance of actual testing concerning the physical and chemical character of the materials. The latter portion of this report, dealing with the cement resources of the separate States, is designed to furnish information of this type.

The scope of the report is fairly well defined by the preceding statements. It is intended to be primarily a discussion of cement materials, not a manual of cement manufacture or a guide to cement testing or utilization. A brief sketch of the processes of Portland-cement manufacture is presented on pages 21-59, in order to make the subject clear to the great number of people who are interested, in one way or another, in the condition and growth of this important industry.

In Parts III and IV of the bulletin, on pages 333 to 372, will be found a comparatively brief discussion of the raw materials and manufacture of two classes of cements allied to Portland cement, i. e., natural cements and puzzolan (slag) cements.

It is with pleasure that the writer acknowledges his indebtedness to the managers and chemists of the various Portland, natural, and slag cement plants throughout the United States. Most of these plants, with their quarries or mines, have been personally examined by the writer, and in every case all possible facilities have been afforded for making the examination as thorough as was necessary. A considerable part of the information obtained in this manner can, of course, for obvious business reasons, be only stated in a general way; but in most cases permission to publish the data obtained has been freely given.

LITERATURE ON CEMENTS.

Frequent references have been given, in the text or in footnotes, to reports or papers which give more detailed information in regard to various phases of the subject. It is a matter of regret that no single book has been published which adequately summarizes the conditions of the modern cement industry in America. This is doubtless due in part to the fact that all our technical industries are in present days subject to such rapid advance that data must be sought in the engineering and other technical journals, and not in books. In part, however, the lack of a cement manual is due to the fact that the leaders in the progress of the American cement industry have been cement manu-

facturers, and have not felt justified in spending their time in summarizing the practice for the benefit of competitors. In view of these conditions, the present writer has endeavored, in a volume now in press,[a] to describe the technologic and financial features of the lime and cement industries. In the present bulletin, however, consideration of these features has been subordinated to the discussion of the geology and of the distribution of the raw materials.

Hydraulic Cement; its Properties, Testing, and Use, by F. P. Spalding, is without doubt the most satisfactory single volume to serve as an introduction to the general subject of cement testing and properties. As might be inferred from its subtitle, it contains practically nothing relative to raw materials or methods of manufacture, but is devoted almost entirely to a consideration of the finished product.

Cements, Mortars, and Concretes, by M. S. Falk, contains valuable data on the physical properties of these materials.

The Cement Industry, a volume containing a number of papers which originally appeared in the Engineering Record, is of great service as an introduction to the study of cement-manufacturing methods.

The Directory of American Cement Industries contains, in addition to its lists of plants, many valuable notes on manufacturing and testing methods.

Books devoted to Portland cement exclusively have been written by Jameson and Butler, but they contain nothing relative to rotary kiln practice, and are therefore of little use to American readers.

To one fairly conversant with the French language, two admirable books will be of service. The first of these, Candlot's Ciments et Chaux Hydrauliques, is probably the best single book, in any language, on cement technology. In its treatment of the theoretical questions involved in cement manufacture it is excellent; but its value for American readers is lessened because the mechanical side of the cement industry is discussed solely from the standpoint of European practice.

The second, of somewhat different character, is Bonnami's Fabrication et Controle des Chaux Hydrauliques et des Ciments. This volume contains a very detailed description of the manufacture and properties of the hydraulic limes, so widely used in Europe, but it also contains valuable discussions on the theoretical side of cement manufacture in general.

DEFINITION OF PORTLAND, NATURAL, AND PUZZOLAN CEMENTS.

Before taking up the subject of the materials and manufacture of cements, it is advisable to define the four great classes which are included in the group of "hydraulic cements," as that term is used by

[a] Cements, Limes, and Plasters: Their Manufacture and Properties. Wiley & Sons, New York. 1905.

the engineer. The relationship of the various cementing materials[a] can be concisely expressed as in the following diagram:

Nonhydraulic cements	Plaster of Paris, cement plaster, Keene's cement, etc. Common lime.
Hydraulic cements	Hydraulic lime. Natural cements. Portland cements. Puzzolan cements.

Nonhydraulic cements.—Nonhydraulic cements do not have the property of "setting" or hardening under water. They are made by burning, at a comparatively low temperature, either gypsum or pure limestone. The products obtained by burning gypsum are marketed as "plaster of Paris," "cement plaster," "Keene's cement," etc., according to details in the process of manufacture. The product of burning limestone is common lime. The plasters and limes will not be further discussed in the present bulletin.

Hydraulic cements.—The hydraulic cements are those which set when used under water, though the different kinds differ greatly in the extent to which they possess this property, which is due to the formation during manufacture of compounds of lime with silica, alumina, and iron oxide.

On heating a pure limestone ($CaCO_3$) containing less than, say, 10 per cent of silica, alumina, and iron oxide together, its carbon dioxide (CO_2) is driven off, leaving more or less pure calcium oxide (CaO) (quicklime or common lime). If the limestone contains much silica, alumina, or iron oxide, the result is quite different.

Natural cements.—Natural cements are produced by burning a naturally impure limestone, containing from 15 to 40 per cent of silica, alumina, and iron oxide, at a comparatively low temperature, about that of ordinary lime burning. The operation can therefore be carried on in a kiln closely resembling an ordinary lime kiln. During the burning the carbon dioxide of the limestone is almost entirely driven off, and the lime combines with the silica, alumina, and iron oxide, forming a mass containing silicates, aluminates, and ferrites of lime. If the original limestone contained much magnesium carbonate the burned rock will contain a corresponding amount of magnesia.

The burned mass will not slack if water be added. It is necessary, therefore, to grind it rather fine. After grinding, if the resulting powder (natural cement) be mixed with water it will harden rapidly. This hardening or setting will also take place under water. Natural cements differ from ordinary limes in two noticeable ways:

(1) The burned mass does not slack on the addition of water.

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[a] For a more detailed discussion see Municipal Engineering, vol. 24, 1903, pp. 335-336, and Am. Geologist, vol. 29, 1902, pp. 146-154.

(2) The powder has hydraulic properties, i. e., if properly prepared, it will set under water.

Natural cements differ from Portland cements in the following important particulars:

(1) Natural cements are not made from carefully prepared and finely ground artificial mixtures, but from natural rock.

(2) Natural cements are burned at a lower temperature than Portland, the mass in the kiln never being heated high enough to even approach the fusing or clinkering point.

(3) Natural cements, after burning and grinding, are usually yellow to brown in color and light in weight, having a specific gravity of 2.7 to 3.1, while Portland cement is commonly blue to gray in color and heavier, its specific gravity ranging from 3 to 3.2.

(4) Natural cements set more rapidly than Portland cement, but do not attain so high tensile strength.

(5) Portland cement is a definite product, its percentages of lime, silica, alumina, and iron oxide varying only between narrow limits, while brands of natural cements vary greatly in composition.

Portland cement.—Portland cement is produced by burning a finely ground artificial mixture containing essentially lime, silica, alumina, and iron oxide in certain definite proportions. Usually this combination is made by mixing limestone or marl with clay or shale, in which case the mixture should contain about three parts of the lime carbonate to one part of the clayey materials. The burning takes place at a high temperature, approaching 3,000° F., and must therefore be carried on in kilns of special design and lining. During the burning, combination of the lime with silica, alumina, and iron oxide takes place. The product of the burning is a semifused mass called "clinker," which consists of silicates, aluminates, and ferrites of lime in certain fairly definite proportions. This clinker must be finely ground. After such grinding, the powder (Portland cement) will set under water.

Puzzolan cements.—The cementing materials included under this name are made by mixing powdered slacked lime with either a volcanic ash or a blast-furnace slag. The product is, therefore, simply a mechanical mixture of two ingredients, as the mixture is not burned at any stage of the process. After mixing, the mixture is finely ground. The resulting powder (puzzolan cement) will set under water.

Puzzolan cements are usually light bluish, and of lower specific gravity and less tensile strength than Portland cement. They are better adapted to use under water than in air, as is explained on later pages.

PART I. MATERIALS AND MANUFACTURE OF PORTLAND CEMENT.

As noted in the Introduction, this bulletin is not intended to be a manual of cement manufacture, but a guide both to those who wish to locate available supplies of cement material and to those who wish to know whether materials occurring on their property are likely to be fit for such use. To persons of the first class, who usually are cement manufacturers, this first part of the bulletin will contain little of value; but it has seemed probable that such a sketch of cement technology will be serviceable to those who are not so well acquainted with the subject. In the discussion of the manufacture of Portland cement, stress has been laid only upon those processes which are directly influenced by the character of the raw materials used. The section on the mixing and grinding of the raw materials, for example, is much more detailed than the portion devoted to burning and clinker grinding. The subjects of cement testing and the uses of cement have been intentionally omitted.

In the following section, various possible raw materials for Portland-cement manufacture will be taken up and their relative suitability for such use will be discussed. In order that the statements may be clearly understood it will be necessary to preface this discussion by a brief explanation regarding the composition of Portland cement. This subject will be treated in greater detail on pages 23–24.

DEFINITION OF PORTLAND CEMENT.

While there is a general agreement as to what is understood by the term Portland cement, a few points of importance are still open questions. The definitions of the term given in specifications are, in consequence, often vague and unsatisfactory.

Use of term Portland.—It is agreed that the cement mixture must consist essentially of lime, silica, and alumina in proportions which can vary but slightly, and that this mixture must be burned at a temperature which will give a semifused product—a "clinker." These points must therefore be included in any satisfactory definition. The point regarding which there is a difference of opinion is whether or not cements made by burning a natural rock can be considered true Portlands. The question whether the definition of Portland cement

should be drawn so as to include or exclude such products is evidently largely a matter of convention; but, unlike most conventional issues, the decision has very important practical consequences. The question at issue may be stated as follows:

If artificial mixture of the raw materials and a very high degree of burning are made the criteria on which to base a definition, there will be excluded from the class of Portland cements certain well-known and very meritorious products, manufactured at several points in France and Belgium by burning a natural rock without artificial mixture and at a considerably lower temperature than is attained in ordinary Portland-cement practice. These "natural Portlands" of France and Belgium have always been considered Portland cements by the most critical authorities, though all agree that they are not of very high-grade.

There is no doubt that there could occur a rock which would contain lime, silica, and alumina in such proportions as to give a good Portland cement on burning. Actually, however, such a perfect cement rock is of extremely rare occurrence. As above noted, certain brands of French and Belgian "Portland" cements are made from such natural rocks without the addition of any other material, but these brands are not of particularly high grade, and in the better Belgian cements the composition is corrected by the addition of other material to the cement rock before burning.

The following definition of Portland cement is important because of the large amount of cement which is accepted annually under the specifications[a] in which it occurs, and is of interest as being the nearest approach in this country to an official definition of the material.

By a Portland cement is meant the product obtained from the heating or calcining up to incipient fusion of intimate mixtures, either natural or artificial, of argillaceous with calcareous substances, the calcined product to contain at least 1.7 times as much of lime, by weight, as of the materials which give the lime its hydraulic properties, and to be finely pulverized after said calcination, and thereafter additions or substitutions for the purpose only of regulating certain properties of technical importance to be allowable to not exceeding 2 per cent of the calcined product.

It will be noted that this definition does not require pulverizing or artificial mixing of the materials prior to burning. It seems probable that the Belgian "natural Portlands" were kept in mind when these requirements were omitted. In dealing with American-made cements, however—and the specifications in question are headed "Specifications for American Portland Cement"—it is a serious error to omit these requirements. No true Portland cements are manufactured in America from natural mixtures without pulverizing and artificially mixing the materials prior to burning. Several plants, however, have placed on the market so-called "Portland cements," made by grinding up

[a] Prof. Paper No. 28, Corps of Engineers, U. S. A., p. 30.

together the underburned and overburned materials formed during the burning of natural cements. Several of these brands contain from 5 to 15 per cent of magnesia; and under no circumstances can they be considered true Portland cements.

In view of the conditions above noted the writer believes that the following definition will be found more satisfactory than the one above quoted:

Portland cement is an artificial product, obtained by finely pulverizing the clinker produced by burning to semifusion an intimate mixture of finely ground calcareous and argillaceous material, this mixture consisting, approximately, of one part of silica and alumina to three parts of carbonate of lime (or an equivalent amount of lime).

COMPOSITION AND CONSTITUTION.

During recent years much attention has been paid by various investigators to the constitution of Portland cement. The chemical composition of any particular sample can, of course, be readily determined by analysis, and by comparison of a number of such analyses general statements can be framed as to the range in composition of good Portland cements.

Portland cements may be said to tend toward a composition approximating to pure tricalcic silicate ($3CaO.SiO_2$) which would nearly correspond to the proportion CaO, 73.6 per cent, SiO_2, 26.4 per cent. As can be seen, however, from commercial analyses, actual Portland cements differ in composition somewhat markedly from this. Alumina is always present in considerable quantity, forming, with part of the lime, the dicalcic aluminate ($2CaO.SiO_2$). This would give, as stated by Newberry, for the general formula of a pure Portland—

$$x\,(3CaO.SiO_2) + y\,(2CaO.Al_2O_3).$$

The composition is still further complicated by the presence of accidental impurities or intentionally added ingredients. These last may be simply adulterants, or they may be added to serve some useful purpose. Calcium sulphate is a type of the latter class. It serves to retard the set of the cement and, in small quantities, appears to have no injurious effect which would prohibit its use for this purpose. In dome kilns sufficient sulphur trioxide is generally taken up by the cement from the fuel gases to obviate the necessity for later addition of calcium sulphate, but in the rotary kiln its addition to the ground cement, in the form of either powdered gypsum or plaster of Paris, is a necessity.

Iron oxide within reasonable limits seems to act as a substitute for alumina, and the two may be calculated together. Magnesium carbonate is rarely entirely absent from limestones or clays, and magnesia is therefore almost invariably present in the finished cement.

Many engineers regard it as positively detrimental in even small amounts, and because of this feeling manufacturers prefer to carry it as low as possible. Newberry has stated that in amounts of less than 3½ per cent it is harmless, and American Portlands from the Lehigh district usually reach well up toward that limit. In European practice it is carried somewhat lower.

It would seem to be firmly established that in a well-burned Portland cement much of the lime is combined with most of the silica to form the compound $3CaO.SiO_2$—tricalcic silicate. To this compound is ascribed, in large measure, the hydraulic properties of the cement; and in general it may be said that the value of a Portland cement increases directly as the proportion of $3CaO.SiO_2$. The ideal Portland cement, toward which cements as actually made tend in composition, would consist exclusively of tricalcic silicate, and would be therefore composed entirely of lime and silica in the following proportions: Lime (CaO), 73.6 per cent; silica (SiO_2), 26.4 per cent.

Such an ideal cement, however, can not be manufactured under present commercial conditions, for the heat required to clinker such a mixture can not be attained in any working kiln. Newberry has prepared such mixtures by using the oxyhydrogen blowpipe; and the electrical furnace will also give clinker of this composition; but a pure lime-silica Portland is not possible under present conditions.

In order to prepare Portland cement in actual practice, therefore, it is necessary that some other ingredient or ingredients be present to serve as a flux in aiding the combination of the lime and silica, and such aid is afforded by the presence of alumina and iron oxide.

Alumina (Al_2O_3) and iron oxide (Fe_2O_3), when present in noticeable percentages, serve to reduce the temperature at which combination of the lime and silica (to form $3CaO.SiO_2$) takes place; and this clinkering temperature becomes further and further lowered as the percentages of alumina and iron are increased. The strength and value of the product, however, also decrease as the alumina and iron increase; so that in actual practice it is necessary to strike a balance between the advantage of low clinkering temperature and the disadvantage of weak cement, and thus to determine how much alumina and iron should be used in the mixture.

It is generally considered that whatever alumina is present in the cement is combined with part of the lime to form the compound $2CaO.SiO_2$—dicalcic aluminate. It is also held by some, but this fact is somewhat less firmly established than the last, that the iron present is combined with the lime to form the compound $2CaO.Fe_2O_3$. For the purposes of the present paper it will be sufficient to say that, in the relatively small percentages in which iron occurs in Portland cement, it may for convenience be considered as equivalent to alumina in its action, and the two may be calculated together.

RAW MATERIALS FOR PORTLAND CEMENT.

For the purposes of the present section it will be sufficiently accurate to consider that a Portland-cement mixture, when ready for burning, will contain about 75 per cent of lime carbonate ($CaCO_3$) and 20 per cent of silica (SiO_2), alumina (Al_2O_3) and iron oxide (Fe_2O_3) together, the remaining 5 per cent including any magnesium carbonate, sulphur, and alkalies that may be present.

The essential elements which enter into this mixture—lime, silica, alumina, and iron—are all abundantly and widely distributed in nature, occurring in different forms in many kinds of rocks. It can therefore readily be seen that, theoretically, a satisfactory Portland-cement mixture could be prepared by combining, in an almost infinite number of ways and proportions, many kinds of raw material. Obviously, too, we might expect to find gradations in the artificialness of the mixture, varying from one extreme, where a natural rock of absolutely correct composition was used, to the other extreme, where two or more materials, in nearly equal amounts, are required.

The almost infinite number of raw materials which are theoretically available are, however, reduced to a very few under existing commercial conditions. The necessity for making the mixture as cheaply as possible rules out of consideration a large number of materials which would be considered available if chemical composition were the only thing to be taken into account. Some materials, otherwise suitable, are too scarce; some are too difficult to pulverize. In consequence, a comparatively few combinations of raw materials are actually used in practice.

In certain localities deposits of argillaceous (clayey) limestone or "cement rock" occur in which the lime, silica, alumina, and iron oxide exist in so nearly the proper proportions that only a relatively small amount (say 10 per cent) of other material is required in order to make a mixture of correct composition. In the majority of plants, however, most or all of the necessary lime is furnished by one raw material, while the silica, alumina, and iron oxide are largely or entirely derived from another. The raw material which furnishes the lime is usually natural—a limestone, chalk, or marl—but occasionally it is an artificial product, such as the chemically precipitated lime carbonate which results as waste from alkali manufacture. The silica, alumina, and iron oxide of the mixture are usually derived from clays, shales, or slates; but in a few plants blast-furnace slag is used as the silica-aluminous ingredient in the manufacture of true Portland cement.

The various combinations of raw materials which are at present used in the United States in the manufacture of Portland cement may be grouped under six heads: (1) Argillaceous limestone (cement rock)

and pure limestone; (2) pure hard limestone and clay or shale; (3) soft chalky limestone and clay; (4) marl and clay; (5) alkali waste and clay; (6) slag and limestone.

LIMESTONES.

Limestone is the most important ingredient, in one form or another, in a Portland-cement mixture. Limestones of certain types are employed in the manufacture of hydraulic limes, natural cements, and slag cements. It will thus be seen that limestone is a very important constituent of all the cementing materials discussed in this bulletin. For this reason it has seemed desirable to discuss in the present section the origin, composition, varieties, and chemical and physical characters of limestone in general. This has been done in considerable detail. The present section will, therefore, serve as an introduction to the discussions of both the Portland and natural cements.

ORIGIN OF LIMESTONES.

Limestones[a] have been formed largely by the accumulation at the sea bottom of the calcareous remains of such organisms as the foraminifera, corals, and mollusks. Many of the thick and extensive limestone deposits of the United States were probably marine deposits formed in this way. Some of these limestones still show the fossils of which they were formed, but in others all trace of organic origin has been destroyed by the fine grinding to which the shells and corals were subjected before their deposition at the sea bottom. It is probable also that a large part of the calcium carbonate of these limestones was a purely chemical deposit from solution, cementing the shell fragments together.

Other limestones, far less extensive, though important in the present connection, owe their origin to the indirect action of organisms. The "marls," so important to-day as Portland cement materials, fall in this class. As the deposits of this class are of limited extent, however, their method of origin may be dismissed here, but will be described later, on pages 34–36.

Deposition from solution by purely chemical means has undoubtedly given rise to numerous limestone deposits. When this deposition took place in caverns or in the open air it gave rise to onyx deposits and to the "travertine marls" of certain localities in Ohio and elsewhere. When it took place in isolated portions of the sea through the evaporation of the sea water it gave rise to the limestone beds which so frequently accompany deposits of salt and gypsum.

[a] For a more detailed discussion of this subject the reader will do well to consult Chapter 8 of Prof. J. F. Kemp's Handbook of Rocks.

VARIETIES OF LIMESTONE.

A number of terms are in general use for the different varieties of limestone, based upon differences of origin, texture, composition, etc. The more important of these terms will be briefly defined.

The marbles are limestones which, through the action of heat and pressure, have become more or less distinctly crystalline, though the term marble is often extended to cover any limestone which will take a good polish. The term marl, as at present used in cement manufacture, is applied to a loosely cemented mass of lime carbonate formed in lake basins, as described on page 34. Calcareous tufa and travertine are more or less compact limestones, deposited by spring or stream waters along their courses. Oolitic limestones, so called because of their resemblance to a mass of fish roe, are made up of small rounded grains of lime carbonate having a concentrically laminated structure. Chalk is a fine-grained limestone composed of finely comminuted shells, particularly those of the foraminifera. The presence of much silica gives rise to a siliceous or cherty limestone. If the silica present is in combination with alumina the resulting limestone will be clayey or argillaceous.

CHEMICAL COMPOSITION OF LIMESTONE.

A theoretically pure limestone is merely a massive form of the mineral calcite. Such an ideal limestone would therefore consist entirely of calcium carbonate or carbonate of lime ($CaCO_3$) or 56 per cent calcium oxide (CaO) plus 44 per cent carbon dioxide or carbonic acid (CO_2). As might be expected, limestones as quarried differ more or less widely from this theoretical composition. These departures from ideal purity may take place along either of two lines: (1) The presence of magnesia in place of part of the lime; (2) the presence of silica, iron, alumina, alkalies, or other impurities.

It seems advisable to discriminate between these two cases, even though a given sample of limestone may fall under both heads.

MAGNESIA IN LIMESTONE.

The theoretically pure limestones are, as above noted, composed entirely of calcium carbonate and correspond to the chemical formula $CaCO_3$. Setting aside for the moment the question of the presence or absence of such impurities as iron, alumina, silica, etc., it may be said that lime is rarely the only base in a limestone. During or after the formation of the limestone a certain percentage of magnesia is usually introduced in place of part of the lime, thus giving a more or less magnesian limestone. In such magnesian limestones part of the cal-

cium carbonate is replaced by magnesium carbonate ($MgCO_3$), the general formula for magnesian limestone being therefore x $CaCO_3$, y $MgCO_3$. In this formula x may vary from 100 per cent to zero, while y will vary inversely from zero to 100 per cent. Where the two carbonates are united in equal molecular proportions, the resultant rock is called dolomite. It has the formula $CaCO_3$, $MgCO_3$ and is composed of 54.35 per cent calcium carbonate and 45.65 per cent magnesium carbonate. If the calcium carbonate has been entirely replaced by magnesium carbonate, the resulting pure carbonate of magnesia is called magnesite, having the formula $MgCO_3$ and being composed of 47.6 per cent magnesia (MgO) and 52.4 per cent carbon dioxide (CO_2).

Rocks of the limestone series may therefore vary in composition from pure calcite limestone at one end of the series to pure magnesite at the other. The term limestone has, however, been restricted in general use to those rocks which have a composition between that of calcite and dolomite. All the more uncommon phases, carrying more than 45.65 per cent magnesium carbonate, are usually described simply as impure magnesites.

The presence of much magnesia in finished Portland cement is considered undesirable, 3½ per cent being the maximum permissible under most specifications. Therefore the limestone to be used in Portland cement manufacture should not carry over 5 or 6 per cent of magnesium carbonate.

Though magnesia is often described as an "impurity" in limestone, this word, as can be seen from the preceding statements, hardly expresses the facts in the case. The magnesium carbonate present, whatever its amount, simply serves to replace an equivalent amount of calcium carbonate, and the resulting rock, whether little or much magnesia is present, is still a pure carbonate rock. With the impurities to be discussed in later paragraphs, however, this is not the case. Silica, alumina, iron, sulphur, alkalies, etc., when present, are actual impurities, not merely chemical replacements of part of the calcium carbonate.

SILICA, IRON, AND OTHER IMPURITIES IN LIMESTONE.

A limestone consisting of pure calcium carbonate or of calcium carbonate with more or less magnesium carbonate may also contain a greater or lesser amount of distinct impurities. From the point of view of the cement manufacturer, the more important of these impurities are silica, alumina, iron, alkalies, and sulphur, all of which have a marked effect on the value of the limestone as a cement material.

The silica in limestone may occur either in combination with alumina as a clayey impurity, or not combined with alumina. As the effect on the value of the limestone would be very different in the two cases, they will be taken up separately.

Silica in limestone.—Silica, when present in a limestone containing no alumina, may occur in one of three forms, and the one in which it occurs is of great importance in connection with cement manufacture.

(1) In perhaps its commonest form silica is present in nodules, masses, or beds of flint or chert. Silica occurring in this form will not readily enter into combination with the lime of a cement mixture, and a cherty or flinty limestone is therefore almost useless in cement manufacture.

(2) In a few cases, as in the hydraulic limestone of Teil, France, a large amount of silica and very little alumina are present, notwithstanding which the silica readily combines with the lime on burning. It is probable that in such cases the silica is very finely divided or occurs as hydrated silica, which is possibly the result of chemical precipitation or of organic action. In the majority of cases, however, a highly siliceous limestone will not make a cement on burning unless it contains alumina in addition to the silica.

(3) In the crystalline limestones (marbles), and less commonly in uncrystalline limestones, silica may occur as a complex silicate in the form of shreds or crystals of mica, hornblende, or other silicate mineral. In this form silica is somewhat intractable in the kiln, and mica and other silicate minerals are therefore to be regarded as inert and useless impurities in a cement rock. These silicates will flux at a lower temperature than pure silica, and are thus not so troublesome as flint or chert. They are, however, much less serviceable than if the same amount of silica were present in combination with alumina as a clay.

Silica with alumina in limestone.—Silica and alumina, combined in the form of clay, are common impurities in limestones and are of special interest to the cement manufacturer. The best-known example of such an argillaceous limestone is the cement rock of the Lehigh district of Pennsylvania. Silica and alumina when present in this combined form unite readily with the lime under the action of heat, and an argillaceous limestone, therefore, forms an excellent basis for a Portland-cement mixture.

Iron in limestone.—Iron when present in a limestone occurs commonly as the oxide (Fe_2O_3) or sulphide (FeS_2); more rarely as iron carbonate or in complex silicates. Iron in the oxide, carbonate, or silicate forms is a useful flux, aiding in the combination of the lime and silica in the kiln. When present as a sulphide, in the form of the mineral pyrite, in quantities exceeding 2 or 3 per cent, it is to be avoided.

PHYSICAL CHARACTERS OF LIMESTONES.

In texture, hardness, and compactness the limestones vary from the loosely consolidated marls through the chalks to the hard, compact limestones and marbles. They differ in absorptive properties and density. The chalky limestones may have a specific gravity as low as

1.85, corresponding to a weight of 110 pounds per cubic foot, while the compact limestones, commonly used for building purposes, range in specific gravity between 2.3 and 2.9, corresponding approximately to a range in weight of from 140 to 185 pounds per cubic foot.

From the point of view of the Portland-cement manufacturer these variations in physical properties are of economic interest chiefly in their bearing upon two points—the percentage of water carried by the limestone as quarried and the ease with which the rock may be crushed and pulverized. To some extent the two properties counterbalance each other; the softer the limestone the more absorbent is it likely to be. These purely economic features will be discussed in more detail on later pages.

EFFECT OF HEAT ON LIMESTONE.

On heating a nonmagnesian limestone to or above 300° C. its carbon dioxide will be driven off, leaving quicklime (calcium oxide, CaO). If a magnesian limestone be similarly treated, the product would be a mixture of calcium oxide and magnesium oxide (MgO). The rapidity and perfection of this decomposition can be increased by passing steam or air through the burning mass. In practice this is accomplished either by the direct injection of air or steam or more simply by thoroughly wetting the limestone before putting it into the kiln.

If, however, the limestone contains an appreciable amount of silica, alumina, and iron, the effects of heat will not be of so simple a character. At temperatures of 800° C. and upward these clayey impurities will combine with the lime oxide, giving silicates, aluminates, and related salts of lime. In this manner a natural cement will be produced (see pp. 333–334). An artificial mixture of a certain uniform composition, burned at a higher temperature, will give a Portland cement.

ARGILLACEOUS LIMESTONE (CEMENT ROCK).

An argillaceous limestone containing approximately 75 per cent of lime carbonate and 20 per cent of clayey materials (silica, alumina, and iron oxide) would, of course, be the ideal material for use in the manufacture of Portland cement, as such a rock would contain within itself in the proper proportions all the necessary ingredients. It would require the addition of no other material, but when burnt alone would give a good cement. This ideal cement material is, of course, never found, but certain argillaceous limestones approach it very closely in composition.

The most important deposit of these argillaceous limestones or "cement rocks" is that which is so extensively utilized in Portland-cement manufacture in the Lehigh district of Pennsylvania and New Jersey. As this area still furnishes about two-thirds of all the Portland cement manufactured in the United States, its raw materials are described in some detail on pages 31–32.

CEMENT ROCK OF THE LEHIGH DISTRICT.

The Lehigh district of the cement trade comprises parts of Berks, Lehigh, and Northampton counties, Pa., and of Warren County, N. J. Within this relatively small area are located about 20 Portland-cement mills, which produce a little over two-thirds of the entire American output. As deposits of the cement rock used by these plants extend far beyond the present Lehigh district, a marked extension of the district will probably take place as the need for larger supplies of raw material becomes more apparent.

The "cement rock" of the Lehigh district is a highly argillaceous limestone of Trenton (lower Silurian) age. The formation is about 300 feet thick in this area. The rock is very dark gray, and usually has a slaty fracture. In composition it ranges from about 60 per cent lime carbonate with 30 per cent clayey material, up to 80 per cent lime carbonate with 15 per cent of silica, alumina, and iron. The lower beds of the formation always contain more lime carbonate than those above. The content of magnesium carbonate in these cement rocks is always high, as Portland cement material goes, ranging from 3 to 6 per cent.

Near and in some cases immediately beneath these cement beds are beds of purer limestone, containing from 85 to 96 per cent lime carbonate. The usual practice in the Pennsylvania and New Jersey plants has been, therefore, to mix a relatively small amount of this purer limestone with the low lime "cement rock" in such proportions as to give a cement mixture of proper composition.

The economic and technologic advantages of using such a combination of materials are very evident. Both the pure limestone and the cement rock, particularly the latter, can be quarried very easily and cheaply. As quarried they carry but little water, so that the expense of drying them is slight. The fact that about four-fifths of the cement mixture will be made up of a natural cement rock permits coarser grinding of the raw mixture than would be permissible in plants using pure limestone or marl with clay. This point is more fully explained on page 47. When natural cement rock is used as part of the mixture less fuel is probably necessary to clinker the mixture than when pure limestone is mixed with clay.

Such mixtures of argillaceous limestone or "cement rock" with a small amount of pure limestone evidently possess important advantages over mixtures of pure hard limestone or marl with clay. They are, on the other hand, less advantageous as cement materials than the chalky limestones discussed on pages 33–34.

The analyses in the table below are fairly representative of the materials employed in the Lehigh district. The first four analyses are of "cement rock," the last two are of the purer limestone used for mixing with it.

Analyses of Lehigh district cement materials.

	Cement rock.				Limestone.	
Silica (SiO_2)	10.02	9.52	14.52	16.10	3.02	1.98
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	6.26	4.72	6.52	2.20	1.90	0.70
Lime carbonate ($CaCO_3$)	78.65	80.71	73.52	76.23	92.05	95.19
Magnesium carbonate ($MgCO_3$)	4.71	4.92	4.69	3.54	3.04	2.03

"CEMENT ROCK" IN OTHER PARTS OF THE UNITED STATES.

Certain Portland-cement plants, particularly in the western part of the United States, use combinations of materials closely similar to those in the Lehigh district. Analyses of the materials used at several of these plants are given in the following table:

Analyses of "cement rock" and limestone from the western United States.

	Utah.		California.		Colorado.	
	Cement rock.	Limestone.	Cement rock.	Limestone.	Cement. rock.	Limestone.
Silica (SiO_2)	21.2	6.8	20.06	7.12	14.20	......
Alumina (Al_2O_3)	8.0	3.0	10.07	2.36	5.21	......
Iron oxide (Fe_2O_3)	......	......	3.39	1.16	1.73	......
Lime carbonate ($CaCO_3$)	62.08	89.8	63.40	87.70	75.10	88.0
Magnesium carbonate ($MgCO_3$)	3.8	0.76	1.54	0.84	1.10	......

In addition to these "cement rocks" many of the chalky limestones discussed on pages 33–34 are sufficiently argillaceous to be classed as "cement rocks." Because of their softness, however, all the chalky limestones will be described together.

PURE HARD LIMESTONES.

Soon after the American Portland-cement industry had become fairly well established in the Lehigh district attempts were made in New York State to manufacture Portland cement from a mixture of pure limestone and clay. These attempts were not commercially successful, and although their failure was not due to any defects in the limestone used, a certain prejudice arose against the use of the hard limestones. In recent years, however, this has disappeared, and a very large proportion of the American output is now made from mixtures of limestone with clay or shale. The use of the hard limestone is doubtless due in great part to recent improvements in grinding machinery, for the purer limestones are usually much harder than

argillaceous limestones like the Lehigh district "cement rock," and it was very difficult to pulverize them finely and cheaply with the crushing appliances in use when the Portland cement industry was first started in America.

A series of analyses of representative pure hard limestones, together with analyses of the clays or shales with which they are mixed, is given in the following table:

Analyses of pure hard limestones and clayey materials.

	Limestones.				Clays and shales.			
Silica (SiO_2)	1.72	0.86	0.56	0.40	63.56	55.80	56.30	60.00
Alumina (Al_2O_3)	1.63	.63	1.23	.44	27.32	30.20	29.86	23.26
Iron oxide (Fe_2O_3)	6.59	1.03	.29					4.32
Lime carbonate ($CaCO_3$)	90.58	97.06	97.23	97.99	3.60	2.54	....	1.70
Magnesium carbonate ($MgCO_3$)	....	....	.75	.42	2.60	....	....	1.50

The first limestone analysis given in the above table represents a curious type, used in several plants in the Middle West. It is a relatively impure limestone, its principal impurity being iron oxide. It contains 8.22 per cent of iron oxide and alumina, as compared with 1.72 per cent of silica, and therefore great care is required in selecting a suitable high-silica clay to mix with it.

SOFT LIMESTONES (CHALK).

Origin and general character.—Chalk, properly speaking, is a pure carbonate of lime composed of the remains of the shells of minute organisms, those of foraminifera being especially prominent. The chalks and soft limestones discussed agree, not only in having usually originated in this way, but also in being rather soft, and therefore readily and cheaply crushed and pulverized. As Portland-cement materials they are therefore almost ideal. One defect, however, which to a small extent counterbalances their obvious advantages, is the fact that most of these soft, chalky limestones absorb water very readily. A chalky limestone which in a dry season will not carry over 2 per cent of moisture as quarried may, in consequence of prolonged wet weather, show as high as 15 or 20 per cent of water. This difficulty can, of course, be avoided if care be taken in quarrying to avoid unnecessary exposure to water and, if necessary, to provide facilities for storing a supply of the raw materials during wet seasons.

Geographic and geologic distribution in the United States.—The chalks and chalky limestones are confined almost entirely to certain

Southern and Western States. They are all of approximately the same geologic ages—Cretaceous or Tertiary—and are mostly confined to one division of the Cretaceous. The principal chalk or soft limestone deposits available for use in Portland-cement manufacture occur in three widely separated areas, in (*a*) Alabama and Mississipppi, (*b*) Texas and Arkansas, and (*c*) Iowa, Nebraska, North and South Dakota.

Composition.—In composition these chalks, or "rotten limestones," vary from a rather pure calcium carbonate, low in both magnesia and clayey materials, to an impure clayey limestone requiring little additional clay to make it fit for use in Portland-cement manufacture. The analyses in the table below show the range of composition of the chalky limestones.

Analyses of chalky limestones.

	Demopolis, Ala.	San Antonio, Tex.	Dallas, Tex.	White Cliffs, Ark.	Yankton, S. Dak.	Milton, N. Dak.
Silica (SiO_2)	12.13	5.77	23.55	7.97	8.20	9.15
Alumina (Al_2O_3)	4.17	2.12	1.50	1.09	7.07	4.80
Iron oxide (Fe_2O_3)	3.28					2.30
Lime carbonate ($CaCO_3$)	75.07	90.15	70.21	88.64	83.59	63.75
Magnesium carbonate ($MgCO_3$)	.92	.15	.58	.73	n. d.	1.25

FRESH-WATER MARLS.

Marls, in the sense in which the term is used in the Portland-cement industry, are incoherent limestones which have been deposited in the basins of existing or extinct lakes. So far as chemical composition is concerned, marls are practically pure limestones, being composed almost entirely of calcium carbonate. Physically, however, they differ greatly from the compact rocks which are commonly described as limestones, as they are granular, incoherent deposits. This curious physical character is due to the conditions under which they have been deposited, and accordingly varies somewhat.

The above definition of marl is that commonly used in the cement industry, but in geological and agricultural reports, particularly in those issued before the Portland-cement industry became prominent in this country, the term has been used for several very different substances. The following three uses of the term have been particularly common, and must be guarded against when such reports are being examined in search of descriptions of deposits of cement materials:

(1) In early days the terms "marls" and "marlytes" were applied to calcareous shales and often to shales which were not particularly calcareous. This use of the term will be found in many of the earlier

geological reports issued by New York, Ohio, and other interior States.

(2) In New Jersey and the States southward bordering on the Atlantic and Gulf of Mexico the term "marl" is commonly applied to deposits of soft, chalky, or unconsolidated limestone, often containing considable clayey and phosphatic matter. These limestones are of marine origin and are not related to the fresh-water marl deposits here discussed.

(3) In the same States mentioned in the last paragraph, but particularly in New Jersey and Virginia, large deposits of the so-called "greensand marls" occur. This material is in no way related to the true marls, which are essentially lime carbonates, but consists almost entirely of an iron silicate, with very small percentages of clayey, calcareous, and phosphatic matter.

Origin of marls.—The exact cause of the deposition of marls has been the subject of much investigation and discussion, particularly in the last few years, since they have become of economic importance. The most important papers concerning this question are as follows:

Blatchley, W. S., and Ashley, G. H., The lakes of northern Indiana and their associated marl deposits: Twenty-fifth Ann. Rept. Indiana Dept. Geol. Nat. Res., pp. 31-321.

Davis, C. A., A contribution to the natural history of marl: Jour. Geol., vol. 8, pp. 485-497.

Davis, C. A., Second contribution to the natural history of marl: Jour. Geol., vol. 9, pp. 491-506.

Davis, C. A., A contribution to the natural history of marl: Rept. Michigan Geol. Survey, vol. 8, pt. 3, pp. 65-102.

Lane, A. C., Notes on the origin of Michigan bog limes: Rept. Michigan Geol. Survey, vol. 8, pt. 3, pp. 199-223.

Disregarding the points in controversy, which are of no practical importance, it may be said that marls are deposited in lakes by spring or stream waters carrying lime carbonate in solution. The actual deposition is due in part to purely physical and chemical causes, and in part to the direct or indirect action of animal or vegetable life. The result in any case is that a calcareous deposit forms along the sides and over the bottom of the lake, this deposit consisting of lime carbonate, mostly in a finely granular form, interspersed with shells and shell fragments.

Geographic distribution of marl deposits.—The geographic distribution of marl deposits is intimately related to the geologic history of the region in which they occur. Marl beds are the result of the filling of lake basins. Lakes are not common in the United States, except in areas which have been glaciated, since they are in general due to the damming of streams by glacial material. Workable marl deposits, therefore, are confined almost exclusively to those portions of the

United States and Canada lying north of the southern limit of the glaciers.

Marl beds are found in the New England States, where they are occasionally of important size, and in New York, where large beds occur in the central and western portions of the State. Deposits are frequent and important in Michigan and in the northern portions of Ohio, Indiana, and Illinois. They occur in Wisconsin and Minnesota, but have not been as yet exploited for cement manufacture.

Composition.—As shown by the analysis below, marls are usually very pure lime carbonates. They therefore require the addition of considerable clay to bring them up to the proper composition for a Portland-cement mixture.

The marls are readily excavated, but necessarily carry a large percentage of water. The mixture, on this account, is commonly made in the wet way, which necessitates driving off a high percentage of water in the kilns. Analyses of typical marls and clays are given in the following table:

Analyses of marls and clays used in cement plants.

	Marl.			Clay.		
Silica (SiO_2)	0.25	3.0	1.60	40.48	52.0	63.75
Alumina (Al_2O_3)	.10		1.55	20.95	17.0	16.40
Iron oxide (Fe_2O_3)					5.0	6.35
Lime carbonate ($CaCO_3$)	94.39	93.0	88.9	25.80	20.0	4.0
Magnesium carbonate ($MgCO_3$)	.38	1.5	.94	.99		2.1

ALKALI WASTE.

A very large amount of waste material results from the manufacturing of caustic soda. This waste material is largely a precipitated form of calcium carbonate, and if sufficiently free from impurities furnishes a cheap source of lime for use in Portland-cement manufacture.

The availability of alkali waste for this purpose depends largely on what process was used at the alkali plant. Leblanc-process waste, for example, carries a very large percentage of sulphides, which prevents its use as a Portland-cement material. Waste resulting from the use of the ammonia process, on the other hand, is usually a very pure mass of lime, mostly in the form of carbonate, though a little lime hydrate is commonly present. As pyrite is not used in the ammonia process, the waste is usually low enough in sulphur to be used as a cement material. The waste may carry a low or a very high percent-

age of magnesia, according to the character of the limestone that has been used in the alkali plant. When a limestone low in magnesium carbonate has been used the resulting waste is a very satisfactory Portland-cement material.

The following analyses are fairly representative of the waste obtained at alkali plants using the ammonia process:

Analyses of alkali waste.

	1	2	3	4
Silica (SiO_2)	0.60	1.75	1.98	0.98
Alumina (Al_2O_3)	3.04	0.61	1.41	1.62
Iron oxide (Fe_2O_3)			1.38	
Lime (CaO)	53.33	50.60	48.29	50.40
Magnesia (MgO)	0.48	5.35	1.51	4.97
Alkalies (Na_2O, K_2O)	0.20	0.64	0.64	0.50
Sulphur trioxide (SO_3)	n. d.	n. d.	1.26	n. d.
Sulphur (S)	n. d.	0.10	n. d.	0.06
Carbon dioxide (CO_2)	42.43	41.70	39.60	n. d.
Water and organic matter	n. d.		3.80	n. d.

Of the analyses quoted in the preceding table, those in the first and third columns represent materials which are used in Portland-cement manufacture in England and the United States. The alkali wastes whose analyses are given in the second and fourth columns are too high in magnesia to be advisable for such use.

BLAST-FURNACE SLAG.

True Portland cements, which must be sharply distinguished from the slag (or puzzolan) cements described on pages 357–372, can be made from a mixture of blast-furnace slag and limestone which is finely powdered, and is then burned in kilns and the resulting clinker pulverized.

The slags from iron furnaces consist essentially of lime (CaO), silica (SiO_2), and alumina (Al_2O_3), though small percentages of iron oxide (FeO), magnesia (MgO), and sulphur (S) are commonly present. Slag may therefore be regarded as a very impure limestone or a very calcareous clay, from which the carbon dioxide has been driven off.

In the United States two plants manufacture true Portland cement from slag, as noted on pages 137 and 294.

The slag used at a German Portland cement plant has the following range in composition:

Analysis of slag used in Portland-cement manufacture.

Silica (SiO_2)	30.0 to 35.0
Alumina (Al_2O_3)	10.0 to 14.0
Iron oxide (FeO)	.2 to 1.2
Lime (CaO)	46.0 to 49.0
Magnesium oxide (MgO)	.5 to 3.5
Sulphur trioxide (SO_3)	.2 to .6

CLAYS AND SHALES.

Clays are ultimately derived from the decay of older rocks, the finer particles being carried off by streams and deposited as beds of clay along channels, in lakes, or along parts of the seacoast or sea bottom. In chemical composition the clays are made up essentially of silica and alumina, though iron oxide is almost invariably present in more or less amount, while lime, magnesia, alkalis, and sulphur occur frequently, though usually only in small percentages.

Shales are clays which have become hardened by pressure. The so-called "fire clays" of the Coal Measures are shales, as are many of the other "clays" of commerce.

For use as Portland-cement materials clays or shales should be free from gravel and sand, as the silica present as pebbles or grit is practically inert in the kiln unless ground more finely than is economically practicable. In composition they should not carry less than 55 per cent of silica, and preferably from 60 to 70 per cent. The alumina and iron oxide together should not amount to more than one-half the percentage of silica, and the composition will usually be better the nearer the ratio $Al_2O_3+Fe_2O_3=\frac{SiO_2}{3}$ is approached.

Nodules of lime carbonate, gypsum, or pyrite, if present in any quantity, are undesirable, though the lime carbonate is not absolutely injurious. Magnesia and alkalis should be low, preferably not above 3 per cent.

Analyses of clays and shales used in various American Portland cement plants are given on pages 33 and 36.

SLATE.

Slate is, so far as origin is concerned, merely a form of shale in which a fine, even, and parallel cleavage has been developed by pressure. In composition, therefore, it varies exactly as do the shales considered on previous pages, and so far as composition alone is concerned, slate would not be worthy of more attention, as a Portland-cement material, than any other shale.

Commercial considerations in connection with the slate industry, however, make slate a very important possible source of cement material. Good roofing slate is a relatively scarce and commands a good price when found. In the preparation of roofing slate for the market so much material is lost during sawing, splitting, etc., that only about 10 to 25 per cent of the amount quarried is salable as slate. The remaining 75 to 90 per cent is of no service to the slate miner. It is sent to the dump heap, and is a continual source of trouble and expense. This very material, however, as can be seen from the analyses quoted below, is often admirable for use, in connection with limestone, in a Portland-cement mixture. As it is a waste product it could be obtained very cheaply by the cement manufacturer.

Composition of American roofing slates.

	Maximum.	Average.	Minimum.
Silica (SiO_2)	68.62	60.64	54.05
Alumina (Al_2O_3)	24.71	18.05	9.77
Iron oxide (FeO, Fe_2O_3)	10.66	6.87	2.18
Lime (CaO)	5.23	1.54	.00
Magnesia (MgO)	6.43	2.60	.12
Alkalies (K_2O, Na_2O)	8.68	4.74	1.93
Ferrous sulphide (FeS_2)		.38	
Carbon dioxide (CO_2)		1.47	
Water of combination		3.51	
Moisture below 110°C		.62	

VALUE OF DEPOSITS OF CEMENT MATERIALS.

The determination of the possible value for Portland-cement manufacture of a deposit of raw material is a complex problem, depending upon a number of distinct factors, the more important of which are as follows: (1) Chemical composition, (2) physical character, (3) amount available, (4) location with respect to transportation routes, (5) location with respect to fuel supplies, (6) location with respect to markets.

Ignorance of the respective importance of these factors frequently leads to an overestimate of the value of a deposit of raw material. Their effects may be briefly stated, as follows:

(*1*) *Chemical composition.*—The raw material must be of correct chemical composition for use as a cement material. This implies that the material, if a limestone, must contain as small a percentage as possible of magnesium carbonate. Under present conditions, 5 or 6 per cent is the maximum permissible. Free silica, in the form of chert, flint, or sand, must be absent, or present only in small quan-

tity—say 1 per cent or less. If the limestone is a clayey limestone, or "cement rock," the proportion between its silica and its alumina and iron should fall within the limits

$$\frac{SiO_2}{Al_2O_3+Fe_2O_3} > 2: \frac{SiO_2}{Al_2O_3+Fe_2O_3} < 3.5.$$

A clay or shale should satisfy the above equation, and should be free from sand, gravel, etc. Alkalies and sulphates should, if present, not exceed 3 per cent.

(2) *Physical character.*—Economy in excavation and crushing requires that the raw materials should be as soft and as dry as possible.

(3) *Amount available.*—A Portland-cement plant running on dry raw materials, such as a mixture of limestone and shale, will use approximately 20,000 tons of raw material a year per kiln. Of this about 15,000 tons are limestone and 5,000 tons shale. Assuming that the limestone weighs 160 pounds per cubic foot, which is a fair average weight, each kiln in the plant will require about 190,000 cubic feet of limestone a year. As the shale or clay may be assumed to contain considerable water, a cubic foot will probably contain not over 125 pounds of dry material, so that each kiln will also require about 80,000 cubic feet of shale or clay.

A cement plant is an expensive undertaking, and it would be folly to locate a plant with less than a twenty years' supply of raw material in sight. In order to justify the erection of a cement plant, *there must be in sight at least 3,800,000 cubic feet of limestone and 1,600,000 cubic feet of clay or shale for each kiln.*

(4) *Location with respect to transportation routes.*—Portland cement is for its value a bulky product, and is therefore much influenced by transportation routes. To locate a plant on only one railroad, unless the railroad officials are financially connected with the cement plant, is simply to invite disaster. At least two transportation routes should be available, and it is best of all if one of these be a good water route.

(5) *Location with respect to fuel supplies.*—Every barrel (380 pounds) of Portland cement marketed implies that at least 200 to 300 pounds of coal have been used in the power plant and the kilns. In other words, each kiln in the plant will, with its corresponding crushing machinery, use up from 6,000 to 9,000 tons of coal a year. The item of fuel cost is therefore highly important, for in the average plant about 30 to 40 per cent of the total cost of the cement will be chargeable to coal supplies.

(6) *Location with respect to markets.*—In order to achieve an established position in the trade, a new cement plant should have (*a*) a local market area, within which it may sell practically on a noncompetitive basis, and (*b*) easy access to a larger though competitive market area.

METHODS AND COST OF EXCAVATING RAW MATERIALS.

The natural raw materials used in Portland-cement manufacture are obtained by one of three methods: (1) Quarrying, (2) mining, and (3) dredging. The method will depend partly on the physical character of the material and partly on the topographic and geologic conditions. Usually, however, there is no opportunity for choice, as one of the methods will offer the only possible mode of handling the material. The three different methods of excavation will first be briefly considered, after which the cost of raw materials at the mill will be discussed.

Quarrying.—In the following pages the term "quarrying" will include all methods of obtaining raw materials from open excavations—quarries, cuts, or pits—whether the material be a limestone, a shale, or a clay. Quarrying is the most natural and common method of excavating the raw materials for cement manufacture. If marl, which is usually worked by dredging, be excluded from consideration, it is probably within safe limits to say that 95 per cent of the raw materials used at American Portland-cement plants is obtained by quarrying. If marls be included, the percentages excavated by the different methods would probably be about as follows: Quarrying, 88 per cent; dredging, 10 per cent; mining, 2 per cent.

In the majority of limestone quarries the material is blasted out and loaded by hand onto cars or carts. In a few limestone quarries a steam shovel is employed to do the loading, and in shale quarries the use of steam shovels is more frequent. In certain clay and shale pits, where the materials are of suitable character, the steam shovel does all the work, both excavating and loading the raw materials.

The rock is usually shipped to the mill as quarried, without any treatment except sledging it to convenient size for loading. At a few quarries, however, a crushing plant is installed, and the rock is sent as crushed stone to the mill. At a few quarries driers have been installed, and the stone is dried before being shipped to the mill. Except the saving of mill space thus attained, this practice seems to have little to commend it.

Mining.—The term "mining" will be used, in distinction from "quarrying," to include methods of obtaining any kind of raw material by underground workings, through shafts or tunnels. Mining is, of course, rarely employed in excavating substances of such low value per ton as the raw materials for Portland-cement manufacture. Occasionally, however, a thin bed of limestone or shale will be overlain by such a thickness of other strata that mining will be cheaper than stripping and quarrying.

Mining is considerably more expensive than quarrying, but it has a few advantages that serve to counterbalance partly the greater cost per

ton of raw material. A mine can be worked steadily and economically in all kinds of weather, while an open cut, or quarry, is commonly in a more or less unworkable condition for about three months of the year. Material won by mining is, moreover, always dry and clean.

Dredging.—The term "dredging" will be here used to include all methods of excavating soft, wet raw materials. In the United States the only raw material for Portland-cement manufacture extensively worked by dredging is marl. Occasionally the clay used is obtained from deposits overlain by more or less water; but this is rarely done except where the marl and clay are interbedded or associated.

A marl deposit, in addition to containing much water diffused throughout its mass, is usually covered by water to a considerable depth. This will frequently require the partial draining of the basin in order to get tracks laid near enough to be of service.

In dredging marl the excavator is frequently mounted on a barge, which floats in a channel resulting from previous excavation. Occasionally, in deposits which either were originally covered by very little water or have been drained, the shovel is mounted on a car which runs on tracks laid along the edge of the deposit.

A deposit worked by dredging always occurs in a basin or depression, and at a lower elevation than the mill, thus necessitating uphill transportation, which may be effected in two ways, the choice depending largely upon the manufacturing processes in use at the plant. At plants using dome or chamber kilns, or where the marl is to be dried before it is sent to the kiln, the excavated material is usually loaded by the shovel on cars and hauled to the mill by horse or steam power. At normal marl plants using a very wet mixture it is probably more economical to dump the marl from the excavator into tanks, add sufficient water to make it flow readily, and pump the fluid mixture to the mill in pipes.

Cost of raw materials at mill.—The most natural way, perhaps, to express the cost of the raw materials delivered at the mill would be to state it as being so many cents per ton or cubic yard, and this is the method followed by quarrymen or miners in general. To the cement manufacturer, however, such an estimate is not so suitable as one based on the cost per ton or barrel of finished cement.

It may be considered that hard and comparatively dry limestones or shales lose 33⅓ per cent in weight on burning, or that 600 pounds of dry raw material will make about 400 pounds of clinker. Allowing something for other losses in manufacture, it is convenient and sufficiently accurate to estimate that 600 pounds of dry raw material will give one barrel of finished cement. The raw material must be increased if it carries any appreciable amount of water. Clays will frequently contain 15 per cent or more of water; while soft chalky limestones, if quarried during wet weather, may carry over 20 per

cent. A Portland-cement mixture composed of a pure chalky limestone and a clay might, therefore, average 10 to 20 per cent of water; consequently about 700 pounds of such a mixture would be required to make one barrel of finished cement.

With marls the loss on drying and burning is much greater. Russell states[a] that according to determinations made by E. D. Campbell 1 cubic foot of marl, as it usually occurs in the natural deposits, contains about 47½ pounds of lime carbonate and 48 pounds of water. In making cement from a mixture of marl and clay, therefore, it would be necessary to figure on excavating and transporting over 1,000 pounds of raw material for every barrel of finished cement.

Thus the cost of raw materials at the mill, per barrel of cement, will vary not only with the cost of excavation but with the kind of materials in use. In dealing with hard dry materials extracted from open quarries near the mills the cost of raw materials may range from 8 to 15 cents per barrel of cement. The lower figure is probably about the lowest attainable under good management and favorable natural conditions; the higher figure is probably a maximum for fairly careful management of a difficult quarry under Eastern labor conditions. When it is necessary to mine the materials the cost will be somewhat increased. Cement rock has been mined at a cost equivalent to 10 cents per barrel of cement, but only under particularly favorable conditions. The cost of mining and transportation may reach 20 cents per barrel.

With regard to wet marls and clays, it is difficult to give even an approximate estimate. It seems probable, however, when the dead weight handled is allowed for, that these soft materials will cost about half as much delivered at the mill per barrel of finished cement as the hard dry limestones and shales.

METHODS OF MANUFACTURE OF PORTLAND CEMENT.

If, as in this bulletin, the so-called "natural Portlands" (see p. 22) are excluded, Portland cement may be regarded as an artificial product obtained by burning to semifusion an intimate mixture of pulverized materials containing lime, silica, and alumina in varying proportions within certain narrow limits, and by crushing finely the clinker resulting from this burning. If this restricted definition of Portland cement be accepted, four points may be regarded as being of cardinal importance: (1) The cement mixture must be of the proper chemical composition; (2) the materials must be carefully ground and intimately mixed before burning; (3) the mixture must be burned at the proper temperature; (4) after burning, the resulting clinker must be finely ground.

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[a] Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 3, p. 657.

As the chemical composition of the mixture can be more advantageously discussed after the other three subjects have been disposed of, it will therefore be taken up last.

PREPARATION OF THE MIXTURE FOR THE KILN.

In the preparation of the mixture for the kiln the raw materials must be reduced to a very fine powder and intimately mixed. The raw materials are usually crushed more or less finely, then mixed, and then ground to powder. Two general methods of treatment, the dry and the wet, are in use at different plants. Unless the limy constituent of the mixture is a marl, already full of water, the dry method is almost invariably followed. In this the materials are kept in as dry a condition as possible throughout the entire process of crushing and mixing, and if they originally contained a little moisture they are dried before being powdered and mixed. In the wet method, on the other hand, the materials are powdered and mixed while in a very fluid state, the mixture containing 60 per cent or more of water.

PERCENTAGE OF WATER IN RAW MATERIALS.

The percentage of water thus carried by the crude raw material will depend largely on the character of the material, partly on the method of handling and storing it, and partly on weather conditions.

In hard limestones, freshly quarried, the water will commonly range from one-half to 3 per cent, rarely reaching or exceeding the higher figure, except in the very wet quarries or during a rainy season. Such limestones, comparatively dry when quarried, are frequently sent to the grinding mills without artificial drying.

Soft, chalky limestones, which absorb water very rapidly, usually contain not more than 5 per cent of water in dry weather, while prolonged wet weather may necessitate the handling at the mill of material carrying as high as 15 to 20 per cent of water.

The clays present much more complicated conditions. In addition to the hygroscopic or mechanically held water, there is also always a certain percentage of chemically combined water. The amount of hygroscopic water will depend on the treatment and exposure of the clay, and may vary from 1 per cent in clays which have been stored and air dried to as high as 30 per cent in fresh clays. The chemically combined water will depend largely on the composition of the clay, and may vary from 5 to 12 per cent. The hygroscopic or mechanically held water of clays can be driven off at a temperature of 212° F., while the chemically combined water is lost only at a low red heat. The total water, therefore, to be driven off from clays may range from 6 to 42 per cent, depending on the weather, the drainage of the clay pit, and the care taken to prevent unnecessary exposure of the excavated material to moisture. The average total amount of moisture will probably be about 15 per cent.

In dealing with shales the mechanically held water rarely amounts to more than about 10 per cent, and is commonly well below that limit. An additional 2 to 7 per cent of water will be carried by any shale in a state of chemical combination.

At a few plants marl is used with clay in a dry process. As noted elsewhere, the marls as excavated carry usually about 50 per cent of water. These present a more difficult problem than the other raw materials, because the vegetable matter usually present in marls is extremely retentive of water.

It will be seen, therefore, that cement materials may carry from 1 to 50 per cent of water when they reach the mill. In a dry process it is necessary to remove practically all of this water before commencing the grinding. One reason for this is that fine pulverizing can not be economically or satisfactorily accomplished unless absolutely dry material is fed to the grinding machinery. Another reason, which is one of convenience rather than of necessity, is that the presence of water in the raw materials complicates the calculation of the cement mixture.

METHODS AND COSTS OF DRYING.

With the exception of the marls and clays used in the wet method of manufacture, Portland-cement materials are usually dried before the grinding is commenced. This is necessary because the raw materials, as they come from the quarry, pit, or mine, will almost invariably carry appreciable, though often very small, percentages of water, which greatly reduces the efficiency of most modern types of grinding mills and tends to clog the discharge screens.

The type of drier commonly used in cement plants is a cylinder, approximately 5 feet in diameter and about 40 feet in length, set at a slight inclination to the horizontal and rotating on bearings. The wet raw material is fed in at the upper end of the cylinder, and it moves gradually toward the lower end under the influence of gravity as the cylinder revolves. In many driers angle irons are bolted to the interior in such a way as to lift and drop the raw material alternately, thus exposing it more completely to the action of the heated gases and materially assisting in the drying process. The dried raw material falls from the lower end of the cylinder into an elevator boot and is then carried to the grinding mills.

The drying cylinder is heated either by a separate furnace or by waste gases from the cement kilns. In either case the products of combustion are introduced into the cylinder at its lower end, are drawn through it, and escape up a stack set at the upper end of the drier.

The drier above described is the simplest and is most commonly used. For handling the small percentages of water contained in most

cement materials it is very efficient, but for dealing with high percentages of water, such as are encountered when marl is to be used in a dry process, double-heating driers probably will be found more economical. This type is exemplified by the Ruggles-Coles drier, a detailed description of which is given in the Mineral Industry, volume 10, pages 84–95. In this drier a double cylinder is employed. The wet raw material is fed into the space between the inner and outer cylinders, while the heated gases pass first through the inner cylinder, and then, in a reverse direction, through the space between the inner and outer cylinders. This double-heating type of drier is employed in almost all of the slag cement plants in the United States, and is also in use in several Portland-cement plants.

When vertical kilns were in use drying floors and drying tunnels were extensively used, but at present they can be found in only a few plants, being everywhere else supplanted by the rotary driers.

The cost of drying will depend on the cost of fuel, the percentage of water in the wet material, and the type of drier. Even under the most unfavorable conditions it may be expected that 5 pounds of water will be evaporated per pound of coal used, while a good drier will usually evaporate 7 or 8 pounds of water per pound of coal.

GRINDING AND MIXING.

DRY METHODS.

Part at least of the grinding is usually accomplished before the drying, but for convenience the subjects have been separated in the present paper. Usually the limestone is sent through a crusher at the quarry or mill, and occasionally the raw material is further reduced in a Williams mill, etc., before drying, but the principal part of the reduction always takes place after the material has been dried.

After the two raw materials have been separately dried they may be mixed immediately, or each may be further reduced separately before mixing. Automatic mixers, of which many types are on the market, give a mixture in proportions determined from analysis of the materials.

The further reduction of the mixture is usually carried on in two stages, the material being ground to 30 mesh in a ball mill, comminuter, Griffin mill, etc., and finally reduced in a tube mill. At a few plants, however, single-stage reduction is practiced in Griffin or Huntington mills, while at the Edison plant at Stewartsville, N. J., the reduction is accomplished in a series of rolls.

The majority of plants use either the Griffin mill and tube mill or the ball and tube mills, and there is probably little difference in the cost of operating these two combinations. The ball mill has never been quite so successful as its companion, the tube mill, and has been replaced at several plants by the comminuter.

After the mixture is reduced, and when it is ready for burning, 90 to 95 per cent of it should pass through a 100-mesh sieve. In the plants of the Lehigh district the mixture is rarely crushed as fine as when limestone and clay are used. Newberry[a] has pointed out in explanation of this that an argillaceous limestone (cement rock) mixed with a comparatively small quantity of purer limestone, as in the Lehigh plants, requires less thorough mixing and less fine grinding than when a mixture of limestone and clay (or marl and clay) is used, for even the coarser particles of the argillaceous limestone will vary so little in chemical composition from the proper mixture as to affect the quality of the resulting cement but little should either mixing or grinding be incompletely accomplished.

A very good example of typical Lehigh Valley grinding of raw material is afforded by a specimen examined[b] by Prof. E. D. Campbell. This specimen of raw mix ready for burning was furnished by one of the best of the eastern Pennsylvania cement plants. A mechanical analysis of it showed the following results:

	Mesh of sieve.		
	50	100	200
Per cent passing	96.9	85.6	72.4
Per cent residue	3.1	14.4	27.6

The material, therefore, is so coarsely ground that only a trifle over 85 per cent passes a 100-mesh sieve.

SLAG-LIMESTONE MIXTURES.

While the manufacture of Portland cement from slag and limestone is similar in general theory and practice to its manufacture from limestone and clay, there are certain interesting differences in the preparation of the mixture. In the following paragraphs the general methods of preparing mixtures of slag and limestone for use in Portland-cement manufacture will first be discussed, after which certain processes peculiar to the use of this mixture will be described separately.

General methods.—After it had been determined that puzzolanic cement, made by mixing slag with lime without subsequent burning, was not an entirely satisfactory structural material, attention was soon directed toward the problem of making a true Portland cement from such slag. The blast-furnace slags commonly available, while carrying enough silica and alumina for a cement mixture, are too low in lime to be suitable for Portland cement. Additional lime

[a] Twentieth Ann. Rept. U. S. Geol. Survey, pt. 6, p. 545.
[b] Jour. Am. Chem. Soc., vol. 25, p. 1106.

must be added, usually in the form of limestone, and the slag and limestone must be well mixed and properly burned. The general methods for properly mixing the materials vary in details. It seems probable that the first method used in attempting to make a true Portland cement from slag was to dump the proper proportion of limestone, broken into small lumps, into molten slag. The idea was that both mixing and calcination could thus be accomplished in one stage, but in practice it was found that the resulting cement was variable in composition and always low in grade. This method has accordingly fallen into disuse, and at present three different general processes of preparing the mixture are practiced at different European and American plants:

1. The slag and limestone are granulated, dried, and ground separately. The two materials are then mixed in proper proportions, the mixture is finely pulverized in tube mills, and the product is fed in a powdered state to rotary kilns.

2. The slag is granulated, dried, and mixed with slightly less than the calculated proper amount of limestone, which has been previously dried and powdered. Sufficient powdered slaked lime (say 2 to 6 per cent) is added to bring the mixture up to correct composition. The intimate mixture and final reduction are then accomplished in ball-and-tube mills. About 8 per cent of water is then added, and the slurry is made into bricks, which are dried and burned in a dome or chamber kiln.

3. Slag is granulated and mixed, while still wet, with crushed limestone in proper proportions. This mixture is run through a rotary calciner, heated by waste kiln gases, in which the temperature is sufficient not only to dry the mixture, but also to partly powder it and to reduce most of the limestone to quicklime. The mixture is then pulverized and fed into rotary kilns.

Of the three general processes above described, the second is unsuited to American conditions. The first and third are adapted to the use of the rotary kiln. The third seems to be the most economical, and has given a remarkably low fuel consumption in practice, but so far has not been taken up in the United States.

Certain points of manufacture peculiar to the use of mixtures of slag and limestone will now be described.

Composition of the slag.—The slags adapted to Portland-cement manufacture are of common occurrence in iron-producing districts. The more basic blast-furnace slags are best suited for this use. The slags utilized will generally run from 30 to 40 per cent lime, but the higher the lime the better. The presence of over 3 per cent of magnesia renders a slag unfit for Portland-cement material, and on this account slags from furnaces using dolomite (magnesian limestone) as a flux can not be used for cement manufacture. The presence of any

notable percentage of sulphur is also a drawback, though part of the sulphur in the slag will be removed during the processes of manufacture.

Granulation of slag.—If slag be allowed to cool slowly, it solidifies into a dense, tough material, without hydraulic properties, which is not readily reduced to the requisite fineness for a cement mixture. If it be cooled suddenly, however, as by bringing the stream of molten slag into contact with cold water, the slag is "granulated"—i. e., it breaks up into small porous particles—and is much more readily pulverized than a slowly cooled slag. Sudden cooling intensifies the chemical activity of its constituents so as to give it hydraulic properties, while part of the sulphur contained in the original slag is removed. The sole disadvantage of the process of granulating slag is that the product contains 20 to 40 per cent of water, which must be driven off before the granulated slag is sent to the grinding machinery.

The granulation of the slag is effected by running the stream of molten slag from the furnace into a sheet-iron trough, in which flows a small stream of water whose rate of flow is so regulated as to give complete granulation of the slag without using an excessive amount of water. The trough may discharge the granulated slag into tanks or into box cars, which are usually perforated at intervals along the sides so as to allow part of the water to drain off.

Drying the slag.—As above noted, the granulated slag may carry from 20 to 40 per cent of water. This is removed by treating the slag in rotary driers. In practice such driers give an evaporation of 6 to 10 pounds of water per pound of coal. The practice of slag drying is very fully described in volume 10 of the Mineral Industry, pages 84–95, where figures and descriptions of various driers are also given, with data on their evaporative efficiency. In one of the methods the slag is dried by waste heat from the kilns after it has been mixed with the limestone. Kiln gases could of course be used in the slag driers, but they have not been utilized except in plants following the method described.

Grinding the slag.—Slag can be crushed with considerable ease to about 50 mesh, but notwithstanding its apparent brittleness it is difficult to grind it finer. Until the introduction of the tube mill it was almost impossible to reduce this material to the fineness necessary for a cement mixture, and the proper grinding of the slag is still an expensive part of the process as compared with the grinding of limestone, shales, or clay.

Composition of the limestone.—As the slag carries all the silica and alumina necessary for the cement mixture, the limestone to be added to it should be simply a pure lime carbonate. The limestone used for flux at the furnace which supplies the slag will usually be found to be of suitable composition for use in making up the cement mixture.

Advantages of using slag-limestone mixtures.—The manufacture of a true Portland cement from a mixture of slag and limestone presents certain undoubted advantages over the use of any other raw materials, while it has also a few disadvantages.

Probably the greatest advantage is in the fact that the most important raw material—the slag—can usually be obtained more cheaply than an equal amount of rock could be quarried or mined. The slag is a waste product, which is hard to dispose of and may be obtained at small expense to the cement plant. Another advantage is due to the occurrence of the lime as oxide, and not as carbonate. The heat necessary to drive off the carbon dioxide from an equivalent mass of limestone is, therefore, saved when slag forms part of the cement mixture, and very low fuel consumption is obtained when slag-limestone mixture is burned.

Of the disadvantages, the toughness of the slag and the necessity for drying it before grinding are probably the most important. A third disadvantage, not always apparent at first, is the difficulty of procuring a proper supply of suitable slag. Unless the cement plant is closely connected in ownership with the furnaces from which its slag supply is to be obtained this may become very serious. When there is a good market for iron the furnace manager will naturally give little thought to the question of supplying slag to an independent cement plant.

The advantages of the mixture, however, seem to outweigh its disadvantages, for the manufacture of Portland cement from slag is now a large and growing industry in both Europe and America. In this country two Portland-cement plants have used slag and limestone as raw materials for some time; several others are in course of construction, and it seems probable that in the near future Alabama will join Illinois and Pennsylvania as an important producer of Portland cement from slag.

WET METHODS OF GRINDING AND MIXING.

Wet methods of preparing Portland-cement mixtures date back to the time when millstones and similar crude grinding contrivances were in use. With such imperfect machinery it was almost impossible to grind dry materials fine enough to give a good Portland-cement material. In this country the advent of good grinding machinery has practically driven out wet methods of manufacture, except in dealing with materials such as marls, which naturally carry a large percentage of water. Two plants in the United States add water to a limestone-clay mixture, but the effect of this practice on the cost sheets of these remarkable plants can hardly be encouraging.

The location, physical condition, and chemical composition of the marls and clays used have important effects upon the cost of the wet

process. Marl deposits of workable size occur only in the Northern States and in Canada, and consequently the climate is unfavorable to continuous working throughout the year, for the marl is usually covered with water, and in winter is procured with difficulty. Marl deposits are necessarily and invariably found in depressions, and the mill must be located at a higher level, which involves increased expense in transporting the raw material to the mill.

Glacial clays, which are usually employed in connection with marl, commonly carry a much larger proportion of sand and pebbles than the sedimentary clays found farther south.

The effect of the water carried by the marl has been noted. The material as excavated consists approximately of equal weights of lime carbonate and of water, and more water is often added to permit the marl to be pumped up to the mill.

At the mill the clay is often dried in order to simplify the calculation of the mixture. The reduction of the clay is commonly accomplished in a disintegrator or in edge-runner mills, after which the material is further reduced in a pug mill, sufficient water being here added to enable it to be pumped readily. It is then ready for mixture with the marl, which has been screened to remove stones, wood, etc. The slurry is further ground in pug mills or wet grinding mills of the disk type, while the final reduction commonly takes place in wet tube mills. The slurry, now containing 30 to 40 per cent of solid matter and 70 to 60 per cent of water, is pumped into storage tanks, where it is kept in constant agitation to avoid settling. The slurry is analyzed at this point, and the mixture in the tanks is corrected if found to be of unsatisfactory composition. After standardizing, the slurry is pumped into the rotary kilns. Owing to the large percentage of water in the slurry, the fuel consumption per barrel of finished cement is 30 to 50 per cent greater, and the output of each kiln correspondingly less than in the case of a dry mixture.

It may be of interest, for comparison with the above description of the wet process with rotary kilns, to insert a description of the semiwet process, as carried on a few years ago at the dome-kiln plant of the Empire Portland Cement Company, of Warners, N. Y. The plant has been remodeled since that date, but the processes formerly followed are still of interest, as they resulted in a high-grade though expensive product.

At the Empire plant the marl and clay were obtained from a swamp about three-fourths of a mile from the mill. A revolving derrick with clam-shell bucket was employed for excavating the marl, while the clay was dug with shovels. The materials were taken to the works over a private narrow-gage road, on cars carrying about 3 tons each,

drawn by a small locomotive. At the mill the cars were hauled up an inclined track, by means of a cable and drum, to the mixing floor.

The clay was dried in three Cummer "Salamander" driers, after which it was allowed to cool, and then carried to the mills. These mills were of the Sturtevant "rock emery" type, and reduced the clay to a fine powder, in which condition it was fed, after being weighed, to the mixer. The marl was weighed and sent directly to the mixer, no preliminary treatment being necessary. The average charge was about 25 per cent clay and about 75 per cent marl.

The mixing was carried on in a mixing pan 12 feet in diameter, in which two large rolls, each about 5 feet in diameter and 16-inch face, ground and mixed the materials thoroughly. The mixture was then sampled and analyzed, after which it was carried by a belt conveyor to two pug mills, where the mixing was completed and the slurry formed into slabs about 3 feet long and 4 to 5 inches in width and height. These on issuing from the pug mill were cut into a number of sections, so as to give bricks about 6 by 4 by 4 inches in size. The bricks were then placed on slats, which were loaded on rack cars and run into the drying tunnels. The tunnels were heated by waste gases from the kilns, and from twenty-four to thirty-six hours were required to dry the bricks.

The bricks after drying were fed into dome kilns, of which there were 20, and which were charged with alternate layers of coke and slurry bricks. The coke charge for a kiln was about 4 or 5 tons. This produced 20 to 26 tons of clinker at each burning, thus giving a fuel consumption of about 20 per cent, as compared with the 40 per cent or more required in the rotary kilns using wet materials. From thirty-six to forty hours were required for burning the charge. After cooling the clinker was shoveled out, picked over by hand, and reduced in a Blake crusher, Smidth ball mills, and Davidsen tube mills.

The cement mixture ready for burning will commonly contain from 74 to 77.5 per cent of lime carbonate, or an equivalent proportion of lime oxide. Several analyses of actual cement mixtures are given in the table below. Analysis No. 1, with its relatively high percentage of magnesia, is fairly typical of Lehigh Valley practice. Analyses Nos. 2 and 3 show mixtures low in lime, while analysis No. 4 is probably the best proportioned of the four, especially in regard to the ratio between silica and alumina plus iron. This ratio, for ordinary purposes, should be about 2.5 or 3 to 1, as the cement sets quicker and has less ultimate strength as the percentage of alumina increases. If the alumina percentage be carried too high, moreover, the mixture will give a fusible, sticky clinker when burned, causing trouble in the kilns.

Analyses of cement mixtures.

	1	2	3	4
Silica (SiO_2)	12.62	13.46	13.85	14.77
Alumina (Al_2O_3) and iron oxide (FeO)	6.00	(?)	7.20	4.35
Lime carbonate ($CaCO_3$)	75.46	73.66	73.93	76.84
Magnesia oxide (MgO)	2.65	(?)	(?)	1.74

BURNING THE MIXTURE.

After the cement mixture has been carefully prepared, as described in preceding pages, it must be burned with equal care. In the early days of the Portland-cement industry a simple vertical kiln, much like that used for burning lime and natural cement, was used for burning the Portland-cement mixture. These kilns, while fairly efficient so far as fuel consumption was concerned, were expensive in labor, and their daily output was small. In France and Germany they were soon supplanted by improved types, but still stationary and vertical, which gave very much lower fuel consumption. In America, however, where labor is expensive, and fuel is comparatively cheap, an entirely different style of kiln has been evolved. This is the rotary kiln. With the exception of a very few of the older plants, which have retained vertical kilns, all American Portland-cement plants are now equipped with rotary kilns.

The history of the gradual evolution of the rotary kiln is of great interest, and is discussed in the papers listed below:

DURYEE, E., The first manufacturer of Portland cement by the direct rotary-kiln process: Engineering News, July 26, 1900.

LESLEY, R. W., History of the Portland-cement industry in the United States. 146 pp. Philadelphia, 1900.

LEWIS, F. H., The American rotary-kiln process for Portland cement: Cement Industry, pp. 188–199, New York, 1900.

MATTHEY, H., The invention of the new cement-burning method: Eng. Min. Jour., vol. 6 , 1899, pp. 555, 705.

STANGER, W. H., and Blount, B., The rotary process of cement manufacture: Proc. Inst. Civil Eng., vol. 145, 1901, pp. 44–136.

The influence of the rotary kiln on the development of Portland-cement manufacture in America: Engineering News, May 3, 1900.

The design, construction, and operation of the vertical stationary kilns of various types are discussed in many reports on Portland cement, but as the subject is, in America at least, a matter of simply historical interest, no description of these kilns or their operation will be given in the present bulletin.[a]

[a] Perhaps the most satisfactory single paper on this subject is that by Stanger, W. H., and Blount, B., Gilbert, W., and Candlot, E., and others (Discussion of the value, design, and results obtained from various types of fixed kilns). Proc. Inst. Civil Eng., vol. 145, 1901, pp. 44–48, 81–82, 95–100.

At the different American cement plants the process of burning is rapidly approaching uniformity, though differences in materials, etc., will always make variations necessary. The kiln in which the material is burned is now almost invariably of the rotary type, the rotary process, which is essentially American in its development, being based upon the substitution of machines for hand labor wherever possible. A brief summary of the process will first be given, after which certain subjects of interest will be taken up in more detail.

SUMMARY OF BURNING PROCESS.

The rotary kiln is a steel cylinder about 6 feet in diameter and, for dry materials, 60 or 80 feet long. For wet mixtures a kiln 80 to 100 feet long, or even longer, is frequently employed. This cylinder is set in a slightly inclined position, the inclination being approximately one-half inch to the foot. The kiln is lined, except near the upper end, with very resistant fire brick, to withstand both the high temperature to which its inner surface is subjected and the destructive action of the molten clinker.

The cement mixture is fed in at the upper end of the kiln, while fuel (which may be either powdered coal, oil, or gas) is injected at its lower end. The kiln, which rests upon geared bearings, is slowly revolved. This revolution, in connection with the inclination at which the cylinder is set, gradually carries the cement mixture to the lower end of the kiln. The intense heat generated by the burning fuel first drives off the water and carbon dioxide from the mixture and then causes the lime, silica, alumina, and iron to combine chemically to form the partially fused mass known as "cement clinker." This clinker drops out of the lower end of the kiln, is cooled so as to prevent injury to the grinding machinery, and is then sent to the grinding mills.

THEORETICAL FUEL REQUIREMENTS.

As a preliminary to a discussion of actual practice in the matter of fuel, it will be of interest to determine the heat units and fuel theoretically required in the manufacture of Portland cement from a dry mixture of normal composition.

In burning such a mixture to a clinker the heat needed will be the amount required for the dissociation of the lime carbonate into lime oxide and carbon dioxide. A small additional amount of heat will be required to drive off the water that is chemically held by the clay or shale and to decompose any calcium sulphate (gypsum) that may be present. The amount required for these purposes is not accurately known, however, but is probably so small that it will be more or less entirely offset by the heat which will be liberated during the combination of the lime with the silica and alumina. We may, therefore, without sensible error, regard the total heat theoretically required for the pro-

duction of a barrel of Portland cement as being that which is necessary for the dissociation of 450 pounds of lime carbonate. With coal of a thermal value of 13,500 B. T. U., burned with only the air supply demanded by theory, this dissociation will require 25½ pounds of coal per barrel of cement, a fuel consumption of only 6.6 per cent.

LOSSES OF HEAT.

In practice, however, heat is lost in a number of ways, and the fuel consumption is immensely greater than is theoretically called for. The more important ways in which heat is lost are as follows:

(1) The kiln gases are discharged at a temperature much above that of the atmosphere, ranging from 300° to 2,000° F., according to the type of materials used and the length of the kiln. (2) The clinker is discharged at a temperature varying from 300° to 2,500° F., the range depending, as before, on materials and the length of the kiln. (3) The air supply injected into the kiln is always greater, and usually very much greater, than that required for the perfect combustion of the fuel, and the available heating power of the fuel is thereby reduced. (4) Heat is lost by radiation from the ends and exposed surfaces of the kiln. (5) The mixture, in plants using a wet process, carries a high percentage of water, which must be driven off.

It is evident, therefore, that the amount of fuel actually necessary for the production of a barrel of cement is much above that required by theory.

ACTUAL FUEL REQUIREMENTS AND OUTPUT.

Rotary kilns are nominally rated at a production of 200 barrels a day per kiln. Even on dry and easily clinkered materials and with good coal, however, such an output is not commonly attained with a 60-foot kiln. Normally, a 60-foot kiln working on a dry mixture will produce from 160 to 180 barrels of cement each day of twenty-four hours. In doing this, if good coal is used, its fuel consumption will commonly be from 120 to 140 pounds of coal per barrel of cement, though it may range as high as 160 pounds, and, on the other hand, has fallen as low as 90 pounds. An output of 175 barrels a day, with a coal consumption of 130 pounds per barrel, may therefore be considered as representing the results of fairly good practice on dry materials with a 60-foot kiln. In dealing with a wet mixture, which may carry anywhere from 30 to 70 per cent of water, the results are more variable, though always worse than with dry materials. In working a 60-foot kiln on a wet material, the daily output may range from 80 to 120 barrels, with a fuel consumption of from 150 to 250 pounds per barrel. Using a longer kiln, partly drying the mixture and utilizing waste heat, will of course improve these figures materially.

When the heavy Western oils are used for kiln fuel, it may be estimated that 1 gallon of oil is equivalent in the kiln to about 10 pounds of coal. The fuel consumption, using dry materials, will range between 11 and 14 gallons of oil per barrel of cement; but the daily output is always somewhat less with oil fuel than where coal is used.

Natural gas in the kiln may be compared with good Pennsylvania coal by allowing about 20,000 to 30,000 cubic feet of gas as equivalent to a ton of coal. This estimate is, however, based upon too little data to be as close as those above given for oil or coal.

EFFECT OF COMPOSITION ON BURNING.

The differences in composition between Portland-cement mixtures are very slight if compared, for example, to the differences between various natural cement rocks. But even such slight differences as do exist exercise a very appreciable effect on the burning of the mixture. Other things being equal, any increase in the percentage of lime in the mixture will necessitate a higher temperature in order to get an equally sound cement. A mixture which will give a cement carrying 59 per cent of lime, for example, will require much less thorough burning than would a mixture designed to give a cement with 64 per cent of lime.

With equal lime percentages, the cement carrying high silica and low alumina and iron will require a higher temperature than if it were lower in silica and higher in alumina and iron. But, on the other hand, if the alumina and iron are carried too high, the clinker will ball up in the kiln, forming sticky and unmanageable masses.

CHARACTER OF KILN FUEL.

The fuel most commonly used in modern rotary kiln practice is bituminous coal, pulverized very finely. Coal for this purpose should be high in volatile matter and as low in ash and sulphur as possible. Russell gives the following analyses of West Virginia and Pennsylvania coals used at present at various cement plants in Michigan:

Analyses of kiln coals.

	1	2	3	4
Fixed carbon	56.15	56.33	55.82	51.69
Volatile matter	35.41	35.26	39.37	39.52
Ash	6.36	7.06	3.81	6.13
Moisture	2.08	1.35	1.00	1.40
Sulphur	1.30	1.34	.42	1.46

The coal as usually bought is either "slack" or "run of mine." In the latter case it is necessary to crush the lumps before proceeding further with the preparation of the coal, but with slack this preliminary crushing is not necessary, and the material can go directly to the drier.

DRYING COAL.

Coal as bought may carry as high as 15 per cent of water in winter or in wet seasons. Usually it will run from 3 to 8 per cent. To obtain good results from the crushing machinery this water must be driven off. For coal drying, as for the drying of raw materials, the rotary drier seems best adapted to American conditions. It should be said, however, that in drying coal it is usually considered inadvisable to allow the products of combustion to pass through the cylinder in which the coal is being dried. This restriction serves to decrease slightly the possible economy of the drier, but an evaporation of 6 to 8 pounds of water per pound of fuel coal can still be counted on with any good drier. The fuel cost of drying coal containing 8 per cent of moisture, allowing $2 per ton for the coal used as fuel, will therefore be about 3 to 4 cents per ton of dried product.

PULVERIZING COAL.

Though apparently brittle enough when in large lumps, coal is a difficult material to pulverize finely. For cement-kiln use, the fineness of reduction is extremely variable. The finer the coal is pulverized the better results will be obtained from it in the kiln, and the poorer the quality of the coal the finer it must be pulverized. The fineness attained in practice may therefore vary from 85 per cent, through a 100-mesh sieve, to 95 per cent or more, through the same. At one plant a very poor but cheap coal is pulverized to pass 98 per cent through a 100-mesh sieve, and in consequence gives very good results in the kiln.

Coal pulverizing is usually carried on in two stages, the material being first crushed to 20 to 30 mesh in a Williams mill or ball mill, and finally reduced in a tube mill. At many plants, however, the entire reduction takes place in one stage, Griffin or Huntington mills being used.

TOTAL COST OF COAL PREPARATION.

The total cost of crushing (if necessary), drying, and pulverizing coal, and of conveying and feeding the product to the kiln, together with fair allowances for replacements and repairs and for interest on the plant, will probably range from about 20 to 30 cents per ton of dried coal, for a 4-kiln plant. This will be equivalent to a cost of from 3 to 5 cents per barrel of cement. While this may seem a heavy

addition to the cost of cement manufacture, it should be remembered that careful drying and fine pulverizing enable the manufacturer to use much poorer, and therefore cheaper, grades of coal than could otherwise be utilized.

CLINKER GRINDING.

The power and machinery required for pulverizing the clinker at a Portland-cement plant using the dry process of manufacture are not much more than those needed for pulverizing the raw materials. This may seem at first sight improbable, for Portland-cement clinker is much harder to grind than any possible combination of raw materials; but it must be remembered that for every barrel of cement produced about 600 pounds of raw materials must be pulverized, while only a scant 400 pounds of clinker will be treated, and that the large crushers required for some raw materials can be dispensed with in crushing clinker. With this exception, the machinery for treating the raw material and that for treating the clinker of a dry-process Portland cement plant are usually almost duplicates.

The difficulty, and in consequence the expense, of grinding clinker will depend in large part on the chemical composition of the clinker and on the temperature at which it has been burned. The difficulty of grinding, for example, increases with the percentage of lime carried by the clinker, and a clinker containing 64 per cent of lime will be very noticeably more resistant to pulverizing than one carrying 62 per cent of lime. So far as regards burning, it may be said in general that the more thoroughly burned the clinker the more difficult it will be to grind, assuming that its chemical composition remains the same.

The tendency among engineers at present is to demand more finely ground cement. While this demand is doubtless justified by the results of comparative tests of finely and coarsely ground cements, it must be borne in mind that any increase in fineness of grinding means a decrease in the product per hour of the grinding mills employed, and a consequent increase in the cost of cement. At some point in the process, therefore, the gain in strength due to fineness of grinding will be counterbalanced by the increased cost of manufacturing the more finely ground product.

The increase in the required fineness has been gradual but steady during recent years. Most specifications now require at least 90 per cent to pass a 100-mesh sieve, a number require 92 per cent, while a few important specifications require 95 per cent.

ADDITION OF GYPSUM.

The cement produced by the rotary kiln is invariably naturally so quick-setting as to require the addition of sulphate of lime. This substance, when added in quantities up to 2½ or 3 per cent, retards the

rate of set of the cement proportionately, and appears to exert no injurious influence on the strength of the cement. In amounts over 3 per cent, however, its retarding influence seems to become at least doubtful, while a decided weakening of the cement is noticeable.

Sulphate of lime may be added in one of two forms, either as crude gypsum or as burned plaster. Crude gypsum is a natural hydrous lime sulphate, containing about 80 per cent of lime sulphate and 20 per cent of water. When gypsum is calcined at temperatures not exceeding 400° F., most of its contained water is driven off. The "plaster" remaining carries about 93 per cent of lime sulphate, with only 7 per cent of water.

In Portland-cement manufacture either gypsum or burned plaster may be used to retard the set of the cement, but gypsum is universally employed in the United States. This is merely a question of cost. It is true that to secure the same amount of retardation of set it will be necessary to add a little more gypsum than burned plaster, but gypsum is much cheaper than burned plaster.

The addition of the gypsum to the clinker is usually made before it has passed into the ball mill, comminuter, or whatever mill is in use for preliminary grinding. Adding it at this point insures much more thorough mixing and pulverizing than if the mixture were made later in the process. At some of the few plants which use plaster instead of gypsum the finely ground plaster is not added until the clinker has received its final grinding and is ready for storage or packing.

PART II. PORTLAND-CEMENT RESOURCES OF THE UNITED STATES.

INTRODUCTION.

In this part of the bulletin the States are taken up in alphabetical order and the available Portland-cement materials of each State are described, whether the materials are used or not. When Portland-cement plants are in operation, a brief sketch of the materials used and processes followed is also given. These descriptions are based, in the large majority of cases, on the results of the writer's field work in 1903 and 1904, in the course of which most of the Portland-cement plants of the United States were visited. Portland-cement plants are in operation in nineteen States (see Pl. I).

The cement resources of the various States can not be described in uniform detail. In some States the limestones have been accurately mapped throughout their extent, and numerous analyses are available. In such cases a more detailed discussion of the cement resources is possible than where geologic mapping is less advanced. For this reason the descriptions of some of the States are unsatisfactory, but it would have been impossible to adequately repair these defects of omission in any reasonable length of time.

References are frequently made, in footnotes, to reports of the States or of the United States Geological Survey. Such reports may usually be obtained, either free or at a nominal price, on application to the officials at the heads of the respective surveys.

Maps showing the distribution of cement materials have been inserted wherever sufficient data were at hand to justify their presentation.

PORTLAND-CEMENT RESOURCES OF ALABAMA.

PORTLAND-CEMENT MATERIALS OF ALABAMA.

By Eugene A. Smith.

In Alabama several extensive series of limestones capable of furnishing excellent raw material for the manufacture of Portland cement occur, while the shales and clays necessary to complete the mixture are found in every county in the State. As a matter of convenience,

the Portland-cement materials of northern Alabama and of central and southern Alabama will be discussed separately, because there is a marked geologic as well as geographic distinction between the two portions of the State.

NORTHERN ALABAMA.

The raw materials for the manufacture of Portland cement occurring in the Paleozoic formations of northern Alabama are limestones, shales, and clays. The limestones belong mainly to the Mississippian ("Lower Carboniferous") and to the Chickamauga formation, the shales to the Pennsylvanian ("Coal Measures"), and the clays to the Cambrian, Mississippian, and Pennsylvanian. Although these materials have not yet been utilized for Portland-cement manufacture in Alabama, they have been so used in other States, and there is no reason to doubt that the future will witness their utilization in Alabama.

GENERAL GEOLOGY.

In northern Alabama the combined effects of geologic structure and erosion have resulted in certain definite topographic types with which the geologic outcrops are closely connected.

Structurally, northern Alabama is made up of a series of parallel synclines and anticlines, trending usually a little north of east. The anticlines are sharp, narrow folds; the synclines are flat, wide basins. The effect of erosion has been to cut away the synclines, and the streams of the region now run along anticlinal valleys bordered by flat-topped synclinal plateaus.

The plateaus throughout most of northern Alabama are capped by conglomerates, shales, and sandstones of the Coal Measures. The Mississippian limestones commonly outcrop along the sides and at the immediate base of the plateaus. The Ordovician ("Lower Silurian") beds occur as long, narrow outcrops in the valleys. The middle of the valley is usually occupied by Cambrian shales and the Knox dolomite. The Chickamauga limestones would normally outcrop as two parallel bands in each valley—between the middle of the valley and the foothills of the plateaus. Faulting has, however, been so common that only one of these bands is usually present, the other being cut out by a fault.

LIMESTONES.

CHICKAMAUGA LIMESTONE.

The Chickamauga limestones outcrop in Alabama in three principal areas. In the Tennessee River Valley some of the smaller streams which flow into the river from the north, like Flint River, Limestone Creek, Elk River, Bluewater Creek, and Shoal Creek, have eroded their valleys into the Chickamauga limestone. These areas are crossed

at only a few points by the railroads leading out from Huntsville and Florence, and no commercial use has as yet been made of the rock.

In the narrow anticlinal valleys below enumerated erosion has in most cases sunk the floors of the valleys into Cambrian strata, and, as a consequence, the Chickamauga limestone occupies a narrow belt on each side, near the base of the Red Mountain ridges. But since a fault usually occurs on one side of these valleys, the Red Mountain ridges and the accompanying Chickamauga limestone are more fully represented on the unfaulted side, which is the eastern side in all except Murphrees Valley. While the Chickamauga forms practically a continuous belt along the undisturbed side, extensive areas are sometimes found on the faulted side also. This is the case, for instance, at Vance, on the Alabama Great Southern Railroad, where the rock is quarried for flux for the furnace of the Central Iron Company at Tuscaloosa. Analysis 1 of the table on page 69 shows its composition here. Other series of analyses from lower ledges in the quarry show only 1.22 per cent of silica, but more magnesia.

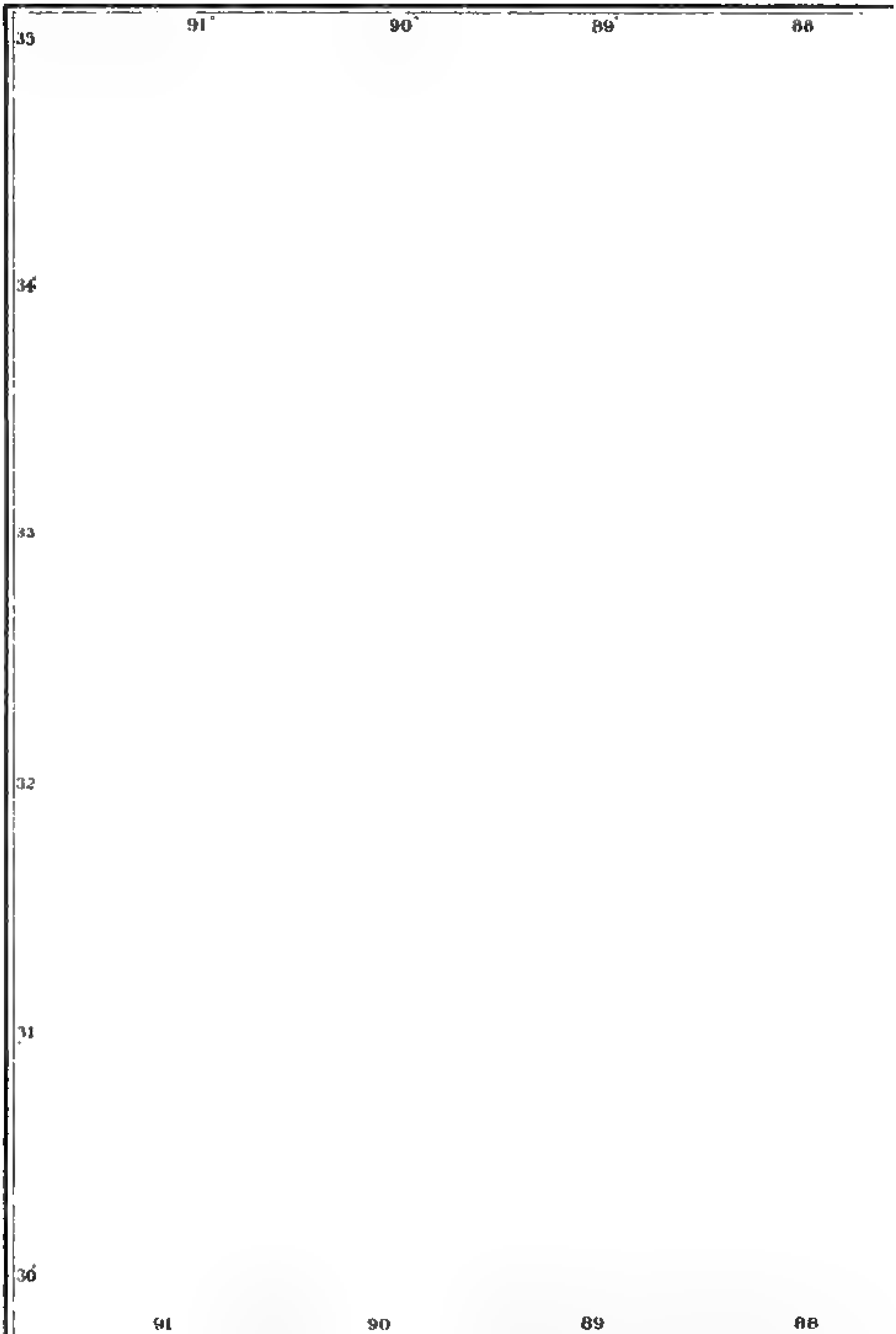
In cases where erosion has not gone so deep as to reach the Cambrian the Chickamauga may be found extending entirely across the valleys. This is the case in the lower part of Browns Valley from Brooksville to beyond Guntersville. Above Guntersville the Chickamauga is seen mainly on the eastern side of the valley. The river touches these outcrops at many points, and at Guntersville the railroad connecting that city with Attalla would afford an additional means of transportation. No developments have yet been made in this area.

The valley separating the Warrior from the Cahaba coal field is known as Roups Valley in the southern and as Jones Valley in the northern part. In these the Chickamauga limestone occupies a narrow, continuous belt, usually near the base of the eastern Red Mountain ridge, though in places it is high up on the ridge and even at its summit, as at Gate City, where the quarries of the Sloss Iron Company are located. Many analyses of the rock from this quarry have been made, and several are given in the table on page 69 (Nos. 2, 3, 4, 5, 6).

In Murphrees Valley the continuous belt of Chickamauga limestone, as above explained, is on the western side, while the faulted remnants are on the eastern side. No quarries have been opened in the Chickamauga limestone here, but the Louisville and Nashville Railroad goes up the valley as far as Oneonta and would afford means of transportation.

In Cahaba Valley, which separates the Cahaba coal field from the Coosa coal field, the Chickamauga is well exposed on the eastern side for the entire length of the valley from Gadsden down. It expands into wide areas near the southern end, where it has been quarried for

U. S GEOLOGICAL SURVEY



GEOLOGIC MAP OF MISSISSIPPI, ALABAMA

Scale
25 0 25 50

1904

LEGEND

POST-EOCENE

Sands, clays, etc.

EOCENE AND OLIGOCENE

Jackson and Vicksburg limestones (cement rock)

EOCENE

Claiborne sandstones, marls, etc.

Lagrange and Midway clays, etc.

CRETACEOUS

Ripley marls and sands

Selma chalk (cement rock)

Eutaw sands

Tuscaloosa clays and sands

CARBONIFEROUS

Coal Measures (shales and sandstones, coal beds)

Mississippian limestone (cement rock)

DEVONIAN, SILURIAN, AND CAMBRIAN UNSEPARATED

Shales, magnesian limestone, etc

Trenton limestone (cement rock)

IGNEOUS AND METAMORPHIC ROCKS

Schists, slates, gneisses, etc.

NOTE. Alabama, from map by Dr. E. A. Smith, 1904. Mississippi, from map by E. C. Eckel and A. F. Crider, 1904. Georgia, from map by J. W. Spencer, 1893, and S. W. McCallie, 1904.

AND PART OF GEORGIA

100 miles

lime burning at Pelham, Siluria, Longview, Calera, and other places on the line of the Louisville and Nashville road. Analyses 7, 8, and 9 of the table on page 69 show the composition of the rock in this region.

The Central of Georgia and the Southern railroads cross this belt about midway of its length at Leeds, in Jefferson County, and near its northern end it is crossed by the Louisville and Nashville Railroad, where a quarry at Rock Springs, on the flank of Colvin Mountain, supplies the rock for lime burning. Analysis 10 (p. 69) shows the character of the rock at this point.

At Pratts Ferry, on Cahaba River, a few miles above Centerville, in Bibb County, the Chickamauga limestone makes high bluffs along the river for several miles, and is in most convenient position for easy quarrying.

Marble works have in former days been established here and should be again put in operation, since the marble is of fine quality and beautifully variegated. No analyses are available, but there is no doubt that much of the rock is sufficiently low in magnesia to be fit for use in cement making. Cahaba River and a short spur from the Mobile and Ohio Railroad would afford transportation facilities for this deposit.

In Big Wills Valley, which separates Sand and Lookout mountains, the Chickamauga limestone occupies perhaps 25 square miles, but it is crossed only by the railroad connecting Gadsden with Guntersville. No analyses are available.

In the great Coosa Valley region the Chickamauga outcrops are found mostly on the western border, near the base of Lookout Mountain, as in Broomtown Valley and in other valleys extending south toward Gadsden. While these belts have been utilized in the past for the old Gaylesville, Cornwall, and Round Mountain furnaces, and possibly for some furnaces now in blast, no analyses are available.

Similarly, farther south, along this western border of the Coosa Valley, and running parallel with the Coosa coal field in Calhoun, St. Clair, and Shelby counties, there are numerous long, narrow outcrops of Chickamauga limestone. The Calcis quarry of the Tennessee Coal, Iron and Railroad Company, on the Central of Georgia Railroad, near Sterritt, is upon one of these outcrops, and furnishes limestone with a very low and uniform percentage of silica and magnesia. Analyses 11, 12, 13, 14, 15, and 16 exhibit the quality of the rock as received at the Ensley Steel Works, but care is taken at the quarry to select ledges low in silica and magnesia, and the analyses therefore represent only the selected ledges and not the average run of the quarry as a whole.

Near Talladega Springs, Marble Valley, and Shelby are other occurrences of the rock, and a quarry a few miles east of Shelby furnace has for many years supplied that furnace with its flux. The quality of the material here is shown by analyses 17, 18, 19, and 20 (p. 69).

The Cambrian limestones contain generally a very considerable proportion of magnesia, and for this reason are not suited for Portland cement manufacture, though admirably adapted for furnace stone.

Along the eastern border of the Coosa Valley, near its contact with the metamorphic rock, there is a belt of limestone which, in places, is a white crystalline marble of great purity, as is shown by analyses 1 to 7, inclusive, of the table on page 70. The Louisville and Nashville Railroad from Calera to Talladega passes close to this belt at many points. This marble has been quarried at several places for ornamental stone. It is mentioned here because it is near the railroad and its description completes the account of the limestone.

MISSISSIPPIAN ("LOWER CARBONIFEROUS") LIMESTONES.

Limestones of suitable quality for cement manufacture occur in the Bangor limestone of the Mississippian ("Lower Carboniferous"). Perhaps the most accessible occurrences of this rock are in the Tennessee Valley to the west of Tuscumbia and south of the river and railroad. Here the quarries of Fossick & Co. were formerly located. Their quarries at this time are farther east, but at a greater distance from the river, in Lawrence County north of Russellville. This outcrop extends thence eastward along the base of Little Mountain as far as Whitesburg, above which place to Guntersville the river flows through a valley floored with Mississippian limestone. The Southern Railway passes over outcrops of this rock in most of the mountain coves east of Huntsville, and from Scottsboro to the Tennessee line the country rock is almost entirely of this formation. The Louisville and Nashville Railroad south of Decatur nearly to Wilhite is mostly in the same formation. These two lines, together with Tennessee River, would provide ample means of transportation for the rock or for the finished product. An analysis of the rock from the Fossick quarries is given in the table on page 68.

In Browns Valley, south of Brooksville, the Bangor limestone is the prevailing rock across the valley, and at Bangor and Blount Springs, on the Louisville and Nashville Railroad, there are extensive quarries which have been worked for many years to supply rock for fluxing purposes to the furnaces of the Birmingham district. Analyses Nos. 2, 3, 4, 5, 6, 7, 8, and 9, on page 68, show the composition of average samples from these quarries; 5 to 9, inclusive, are of carload samples.

From Brooksville to the Tennessee line a great thickness of this limestone is exposed along the western escarpment and below the top of Sand Mountain, which is capped by sandstones of the Coal Measures. In this area the river runs near the foot of the mountain and would afford the means of transportation.

In similar manner the Bangor limestone outcrops along the western flank of Lookout Mountain in Little Wills Valley, from near Attalla

to the Georgia line, and south of Attalla it forms the lower part of the escarpments of Blount and Chandlers Mountain. The Alabama Great Southern Railroad passes very near to the outcrop from the Georgia line down to Springville, Ala. South of Springville large outcrops occur in Shades Valley, and at Trussville are quarries which have supplied the Birmingham furnaces. Analyses 10 to 17, inclusive, page 68, are of material from Trussville; and analyses 12 to 17, inclusive, represent average samples from carload lots delivered to furnace.

In Murphrees Valley the main outcrop of this rock is on the western side, and quarries at Compton have for many years been worked to supply the Birmingham furnaces. Analyses 18, 19, and 20 of the rock from these quarries show somewhat varying composition, but by proper selection suitable material could easily be obtained.

In the valleys lying east of Shades Valley and in parts of Shades Valley itself this formation becomes prevailingly shales and sandstones, limestones being of limited occurrence and of inferior quality.

CLAYS AND SHALES.

The most important clays in the Paleozoic region occur in the Coal Measures, in the Mississippian, and in the Ordovician and Cambrian formations. But, inasmuch as a later formation—the Tuscaloosa of the Cretaceous—borders the Paleozoic on the west and south, and as it contains a great variety as well as abundance of clays, it will be described here, although it is not Paleozoic.

ORDOVICIAN ("LOWER SILURIAN") AND CAMBRIAN SHALES.

Associated with the cherty limestones and brown iron ores of these formations are beds of fine white clay, much of it china clay. Analysis 7 of the second table on page 70 shows the composition of a white clay from the brown ore bank at Rock Run, in Cherokee County, where the clay is about 30 feet in thickness. Analyses 8 and 9 are also from Rock Run. No. 10, from near Gadsden, No. 11, from Blount County, and No. 12, from Oxanna, in Calhoun County, are of clays which seem to be adapted to cement making. While no great number of the clays of these formations have been analyzed, they are known to be widely distributed in Calhoun, Talladega, Jefferson, Tuscaloosa, and other counties in connection with the brown ore deposits.

MISSISSIPPIAN ("LOWER CARBONIFEROUS") SHALES.

Associated with the cherty limestones of the lowermost division of the Carboniferous of some of the anticlinal valleys are beds of clay of excellent quality, much of it being of the nature of china clay.

Probably the best exposures of these clays are in Little Wills Valley, between Fort Payne and the Georgia border, and on the line of the Alabama Great Southern Railroad, where for many years quarries

have been in operation in supplying material for tile works and potteries. The clays lie near the base of the formation, close above the black shale of the Devonian, and average about 40 feet in thickness, though in places they reach 200 feet. The clay beds alternate with seams of chert which are from 2 to 8 inches in thickness, while the clay beds vary from 12 to 18 inches. The upper half of the clay is more gritty than the lower half, which often contains material suitable for the manufacture of the finer grades of porcelain ware. Analyses 3–6 in the second table on page 70 show the composition of several varieties of clay from this section.

PENNSYLVANIAN ("COAL MEASURES") SHALES.

In this group are numerous beds of shale which have been utilized in the manufacture of vitrified brick and fire brick, but many of them will probably be adapted to cement making. A great body of these shales occurs in connection with the coal seams of the Horse Creek or Mary Lee group, in Jefferson and Walker counties, and in position where they are conveniently situated with reference to limestone and coal and also to transportation lines. They are therefore well worth the attention of those contemplating the location of cement plants.

On the property of Mr. W. H. Graves, near North Birmingham, overlying the coal seam mined by him, are two beds of shale—one yellowish, the other gray. These two shales have been tested and analyzed, and their composition is shown in Nos. 1 and 2 of the second table on page 70.

Similar shales are used also at Coaldale, in Jefferson County, and at Pearce's mill, in Marion. Of these we have reports of physical tests, but no analyses.

So also most of the coal seams mined in Alabama rest upon clay beds which have not as yet been specially examined as to their fitness for cement making; but, in view of the proximity of the coal mines to the limestones, it might be worth while to investigate these underclays of the coal seams.

CRETACEOUS CLAYS.

In many respects the most important formation of Alabama with regard to clays is the lowermost division of the Cretaceous, which has been called the Tuscaloosa, and which is, in part at least, of the same geologic horizon as the Raritan clays of New Jersey. The prevailing strata of this formation are yellowish and grayish sands, but subordinated to them are great lenses of massive clay, varying in quality from almost pure-white burning clay to dark-purple and mottled varieties high in iron.

The formation occupies a belt of country extending from the northwestern corner of the State around the edges of the Paleozoic formations to the Georgia line at Columbus. Its greatest width is at the

northwest boundary of the State, where it covers an area 30 or 40 miles wide in Alabama and of about the same width in Mississippi. The breadth at Wetumka and thence eastward to the Georgia line is only a few miles. The most important part of this belt is where it is widest, in Elmore, Bibb, Tuscaloosa, Pickens, Fayette, Marion, Lamar, Franklin, and Colbert counties, and the deposits are traversed by the lines of the Mobile and Ohio, the Alabama Great Southern, the Louisville and Nashville, the Southern, and the Kansas City, Memphis and Birmingham railroads, as well as by the Warrior and Tombigbee rivers.

These clays have been described in some detail. Many analyses and physical tests have been presented in Bulletin No. 6 of the Alabama Geological Survey. From this bulletin have been selected certain analyses which appear to indicate the fitness of the clays for cement making.

In Elmore County in the vicinity of Coosada, along the banks of the river, about Robinson Springs, Edgewood, and Chalk Bluff, are many deposits of these clays, some of which have been used in potteries for many years. Analyses 13, 14, and 15, on page 70, are of clays from Coosada, Edgewood, and Chalk Bluff, respectively.

In Bibb County clay for fire brick has been quarried very extensively at Bibbville and near Woodstock. For this purpose the material is carried to Bessemer by the Alabama Great Southern Railroad. Analysis 16, from Woodstock, and 17, from Bibbville, will represent the average quality of the clay from these beds, which are very extensive both in thickness and in surficial distribution. The Mobile and Ohio crosses other extensive deposits in the southern part of the county, but no analyses are available.

The most important of the clay beds in Tuscaloosa County are traversed by the Mobile and Ohio Railroad and by the Alabama Great Southern.

Analysis 18, from Hull's, and analysis 19, from the Cribbs beds, are on the Alabama Great Southern, and 20 and 21 are from cuts of the Mobile and Ohio, a few miles west of the city of Tuscaloosa.

Many large beds are exposed along the Mobile and Ohio road in Pickens County also, but very few have been investigated. Analysis 22 is from Roberts's mill, in this county.

In Lamar and Fayette counties the same conditions prevail as in Pickens and Tuscaloosa. Analysis 23 is of pottery clay from the Cribbs place, in Lamar; 24 is of clay from Wiggins's, 4 miles west of Fayette; 25 and 26 are clays from W. Doty's place, 14 miles west of that town, in Fayette County.

Marion is one of the banner counties of the State for fine clays, but it is touched by railroads only along its southern border and in the extreme northeastern corner. Although at present not available

because inaccessible, the clays mentioned below (tabulated on page 71) are worthy of consideration: 27, from Bexar; 28, from Briggs Fredericks', in sec. 8, T. 10, R. 13 W. The last is from the great clay deposit which gives the name to Chalk Bluff and which underlies about two townships; 29 is from a locality about 16 miles southwest of Hamilton, the county seat.

No. 30 is from a locality near the Mississippi line, in sec. 20, T. 8, R. 15 W., in Franklin County, from land of Mr. Thomas Rollins.

Of the numerous fine clays of Colbert County analyses are given of two from Pegram station, on the Southern Railway near the Mississippi State line. These are Nos. 31 and 32.

ANALYSES.

Analyses of Mississippian limestones from Alabama.

Number.	Silica (SiO_2).	Iron oxide and alumina (Fe_2O_3 and Al_2O_3).	Lime carbonate ($CaCO_3$).	Magnesium carbonate ($MgCO_3$).	Sulphur (S).
1	0.50	1.45	96.58	2.58	....
2	1.73	.78	96.54	....	....
3	.77	.35	97.60	....	....
4	1.14	.34	98.53	....	....
5	1.02	1.38	95.25	1.73	....
6	1.40	1.17	94.67	2.26	....
7	.68	1.02	96.54	1.26	....
8	.81	.89	97.45	.35	....
9	.82	.60	97.37	.75	0.029
10	2.16	2.31	89.15	4.20	....
11	3.12	2.32	85.87	4.20	....
12	.85	.65	96.64	1.36	.024
13	1.08	.61	96.91	.90	.019
14	.73	.65	97.60	.52	.018
15	.64	.62	97.48	.76	....
16	1.12	.90	96.38	1.10	....
17	.42	.37	97.32	1.39	.020
18	2.05	.76	89.64	8.15	....
19	4.45	3.30	86.35	....	....
20	2.80	.70	94.59	....	....

1. Average sample from Fossick quarry, near Rockwood, Franklin County. Government Arsenal, Watertown, Mass., analyst.
2. Average sample from Blount Springs quarry—a compact limestone. Henry McCalley, analyst.
3. Average sample from Blount Springs quarry—a granular oolitic limestone. Henry McCalley, analyst.
4. Average sample upper 75 feet, Blount Springs quarry. J. L. Beeson, analyst.
5–9. Average sample Blount Springs quarry. J. R. Harris, analyst.
10, 11. From Worthington quarry, near Trussville, Jefferson County. C. A. Meissner, analyst.
12–17. From Vanns, near Trussville. J. R. Harris, analyst.
18. Average of about 150 feet thickness of rock used for flux, Compton quarry, Blount County. J. L. Beeson, analyst.
19, 20. Stockhouse sample, Compton quarry. Wm. B. Phillips, analyst.

Analyses of Chickamauga limestones from Alabama.

Number.	Silica (SiO_2).	Iron oxide and alumina (Fe_2O_3 and Al_2O_3).	Lime carbonate ($CaCO_3$).	Magnesium carbonate ($MgCO_3$).	Sulphur (S).
1	4.48	1.22	88.85	3.52	....
2	5.70	1.87	91.16	....	....
3	2.43	3.30	89.88	....	....
4	3.65	.91	92.38	....	....
5	3.29	1.49	92.61	....	....
6	3.82	1.96	90.44	....	....
7	.39	.13	99.11	.75	....
8	.15	Tr.	99.16	.75	....
9	.78	.35	97.52	1.27	....
10	1.00	.30	97.00	Tr.	Tr.
11	.43	.42	98.49	.16	....
12	.58	.25	95.78	2.89	....
13	.38	.47	98.35	.30	....
14	.34	.46	96.53	2.17	....
15	.39	.37	94.27	4.47	....
16	.98	.52	96.92	1.08	....
17	2.50	1.40	96.70	....	....
18	2.09	1.01	93.77	2.48	....
19	1.08	.63	98.91	.58	....
20	2.25	.68	95.40	.94	....

1. Average of several carloads flux rock from quarry at Vance, Tuscaloosa County, of Central Iron Company at Tuscaloosa. H. Buel, analyst.
2. Gate City quarry, Jefferson County. Average sample from the crusher. Henry McCalley, analyst.
3-6. Gate City quarry. J. W. Miller, analyst.
7, 8. Longview quarries, Shelby County. Used in lime burning. Report of Alabama State Geologist, 1875.
9. Jones quarry, near Longview. Report of Alabama State Geologist, 1875.
10. Rock Spring quarry, Etowah County. Used in lime burning and for flux. Wm. B. Phillips, analyst.
11-16. Rock from Calcis quarry, St. Clair County. J. R. Harris, analyst.
17-20. Shelby quarry, Shelby County. Used for flux in Shelby furnaces. Report of Alabama States Geologist, 1875.

Analyses of crystalline marbles.

Number.	Silica (SiO_2).	Iron oxide and alumina (Fe_2O_3 and Al_2O_3).	Lime carbonate ($CaCO_3$).	Magnesium carbonate ($MgCO_3$).
1	Tr.	....	99.47	0.30
2	2.70	0.40	90.80	Tr.
3	2.95	1.15	95.25	.62
4	4.65	.75	94.40	.41
5	2.80	.48	95.60	.66
6	1.35	.30	97.60	Tr.
7	.28	.28	99.19	.14

1. Herd's upper quarry, Talladega County. Tuomey's Second Report, Geology of Alabama.
2. Herd's quarry, sec. 16, T. 21, R. 4 E., Talladega County. Wm. B. Phillips, analyst.
3. Taylor's mill, Talladega County, white marble. Wm. C. Stubbs, analyst.
4. Taylor's mill, Talladega County, blue marble. Wm. C. Stubbs, analyst.
5. Taylor's mill, Talladega County. A. F. Brainerd, analyst.
6. Nix quarry, sec. 36, T. 20, R. 4 E., Talladega County, white marble. Wm. B. Phillips, analyst.
7. Gannt's quarry, sec. 2, T. 22, R. 3 E., Talladega County, white marble. A. F. Brainerd, analyst.

Analyses of clays—Paleozoic and lower Cretaceous.

Number.	Silica (SiO_2).	Alumina (Al_2O_3).	Iron oxide (Fe_2O_3).	Lime (CaO).	Magnesia (MgO).	Alkalies (K_2O, Na_2O).	Ignition.	Total.
1	61.55	20.25	7.23	Tr.	0.99	1.25	6.19	98.66
2	57.80	25.00	4.00	2.10	.80	1.80	7.50	99.00
3	79.80	11.75	1.75	.75	Tr.	1.50	4.11	99.16
4	82.04	12.17	Tr.	Tr.	.33	.60	4.33	99.47
5	66.25	22.90	1.60	Tr.	Tr.	.75	9.05	100.55
6	82.11	11.41	1.40	Tr.	.66	1.80	4.00	101.38
7	60.50	26.55	.30	.90	.65	2.70	7.90	99.50
8	72.20	22.04	.16	.50	.40	.60	5.80	101.70
9	57.00	17.80	5.60	2.10	1.20	6.00	9.45	99.15
10	67.95	20.15	1.00	1.00	Tr.	1.87	8.00	99.97
11	61.50	26.20	2.10	.50	.43	.70	7.29	98.72
12	84.21	9.75	.69	.70	.14	....	4.10	99.59
13	66.61	21.04	2.88	.40	.58	.70	7.00	99.21
14	62.60	26.98	.72	.40	.36	.65	9.30	101.01
15	60.38	20.21	6.16	.09	.72	1.80	10.21	99.57
16	65.82	24.58	1.25	....	Tr.	.60	8.16	100.41
17	74.25	17.25	1.19	.40	Tr.	.52	6.30	99.39
18	61.25	25.60	2.10	.25	.82	1.35	8.10	99.47
19	65.35	21.30	2.72	.60	.86	Tr.	8.79	99.62
20	60.03	24.66	3.69	.13	.38	Tr.	11.34	100.23
21	58.13	24.68	3.85	.15	.32	1.78	11.78	100.51
22	68.23	20.35	3.20	.34	Tr.	.74	7.16	100.02
23	60.90	18.98	7.68	Tr.	Tr.	Tr.	13.63	100.92

Analyses of clays—Paleozoic and lower Cretaceous—Continued.

Number.	Silica (SiO_2).	Alumina (Al_2O_3).	Iron oxide (Fe_2O_3).	Lime (CaO).	Magnesia (MgO).	Alkalies (K_2O, Na_2O).	Ignition.	Total.
24..........	63.27	19.68	3.52	1.30	Tr.	1.20	9.80	98.77
25..........	67.10	19.37	2.88	Tr.	0.73	.67	7.79	98.54
26..........	65.58	19.23	4.48	Tr.	Tr.	....	6.90	96.19
27..........	68.10	21.89	2.01	.80	.28	.40	5.75	99.23
28..........	65.49	24.84	Tr.	1.26	Tr.	Tr.	7.80	99.39
29..........	70.00	21.31	2.88	.20	Tr.	Tr.	6.85	101.24
30..........	67.50	19.84	6.15	.12	.10	....	7.65	101.36
31..........	66.45	18.53	2.40	1.50	1.25	Tr.	9.46	99.59
32..........	64.90	25.25		Tr.	Tr.	....	8.90	99.05

Coal Measures.
1. Dark-yellow shale from Coal Measures, W. H. Graves, near Birmingham, Jefferson County.
2. Light-gray shale from same locality.

Mississippian.
3-5. Fire clay, near Valley Head, Dekalb County.
6. China clay, Eureka mines, Dekalb County.

Ordovician and Cambrian.
7. China clay, Rock Run, Cherokee County (Dykes ore bank).
8. Fire clay, Rock Run, Cherokee County.
9. Pottery clay, Rock Run, Cherokee County.
10. China clay, J. R. Hughes, Gadsden, Etowah County.
11. Stoneware clay, Blount County.
12. Stevens, fire clay, Oxanna, Calhoun County; probably too much free sand.

Lower Cretaceous (Tuscaloosa).
13. Stoneware clay, Coosada, Elmore County.
14. Pottery clay, McLean's, near Edgewood, Elmore County.
15. Stoneware clay, Chalk Bluff, Elmore County.
16. Fire clay, Woodstock, Bibb County.
17. Fire clay, Bibbville, Bibb County.
18. Fire clay, Hulls Station, Alabama Great Southern Railroad, Tuscaloosa County.
19. Pottery clay, H. H. Cribbs, Alabama Great Southern Railroad, Tuscaloosa County.
20. Pottery clay, J. C. Bean, Mobile and Ohio Railroad, Tuscaloosa County.
21. Fire clay, J. C. Bean, Mobile and Ohio Railroad, Tuscaloosa County.
22. Stoneware clay, Roberts's mill, Pickens County.
23. Pottery clay, Cribb's place, Lamar County.
24. Stoneware clay, H. Wiggins, Fayette County.
25-26. Pottery clay, W. Doty, Fayette County.
27. Blue clay, railroad cut near Glen Allen, Marion County.
28. China clay, Briggs Frederick, Marion County.
29. Pottery clay, 10 miles southwest of Hamilton, Marion County.
30. Pottery clay, Thomas Rollins, Franklin County.
31. Pottery clay, J. W. Williams, Pegram, Colbert County.
32. China clay, Pegram, Colbert County.

CENTRAL AND SOUTHERN ALABAMA.

The raw materials suitable for the manufacture of Portland cement which occur in central and southern Alabama are argillaceous limestones, pure limestones, and clays.

The limestones valuable as cement materials occur mainly at two horizons, viz, in the Selma chalk or Rotten limestone of the Cretaceous, and in the St. Stephens formation of the Tertiary. The clays available are the residual clays derived from the decomposition of these two limestone formations, the stratified clays of the Grand Gulf formation, and the alluvial clays occurring in the river and creek bottoms. It is possible that later investigation may show that some of the other stratified clays of the Cretaceous and Tertiary formations are suitable for cement making, and this is especially likely to be the case with the clays of the lowermost Cretaceous or Tuscaloosa formation.

SELMA CHALK OR "ROTTEN LIMESTONE."

GEOLOGIC HORIZON.

The Cretaceous system in Alabama is susceptible of classification into four divisions. These are, in ascending order, the Tuscaloosa, the Eutaw, the Selma chalk, and the Ripley.

The Tuscaloosa is of fresh-water origin and is made up in the main of sands and clays in many alternations. In places the clays occur in deposits of sufficient size and of such a degree of purity as to make them of commercial value. The Eutaw is of marine origin and is composed of more or less calcareous sands and clays, but nowhere shows beds of limestone properly so called. The Selma chalk is of marine origin and is composed, in part at least, of the microscopic shells of Foraminifera. This formation, throughout the western part of the belt covered by it in Alabama, is about 1,000 feet in thickness, and is made up of beds of chalky and more or less argillaceous limestone. In a general way it may be said that the lower and upper thirds of the formation contain 25 per cent or more of clayey matters mixed with the calcareous material, while the middle third will hold less than 25 per cent of these clayey impurities. The Ripley, like the preceding, is a marine formation, in which, generally, the calcareous constituents predominate, but in places it contains sandy and clayey beds.

From this summary it will be seen that the Selma chalk is the only one of the Cretaceous formations in Alabama which offers limestone in such quantity and of such composition as to be fit for Portland cement material.

LITHOLOGIC DESCRIPTION.

As has been stated above, the Selma chalk is a calcareous formation throughout its entire thickness of about 1,000 feet. The rock, however, varies in composition between somewhat wide limits; for this reason three divisions may readily be distinguished. The rock of the upper division is highly argillaceous, holding 25 per cent or more of clayey matters; portions of it are composed of calcareous clays or marls rather than limestone, and in these beds are found great numbers of fossils, mainly oysters. Along Tombigbee River these beds make the bluffs from Paces Landing down nearly to Moscow, and on the Alabama they form the banks of the river from Elm Bluff down to Old Lexington Landing. The strata exhibited in these bluffs consist of dark-colored, fossiliferous, calcareous clays alternating with lighter-colored and somewhat more indurated ledges of purer, less argillaceous rock. At Elm Bluff, which is about 125 feet high, the upper half of the bluff is of this character. The lower half of the bluff is composed of rock more uniform in composition and freer from clay, and is the top of the middle part of the Selma formation, which is made up of limestone of more uniform character, containing generally less than 25 per cent of clayey material.

In this middle division of the Selma formation the fossils are rarer than in either of the others, oysters and anomias being the most common forms. This variety of the rock forms the bluffs along Alabama River from Elm Bluff up to Kings Landing. It is seen in its most typical exposure at White Bluff, where it is at least 200 feet in thickness and makes on the right bank of the river an almost perpendicular bank. On Tombigbee River it extends from near Bartons Bluff past Demopolis up to Arcola and Hatchs Bluff. Its lowermost beds, a compact limestone of great purity, form the upper parts of Bartons and Hatchs bluffs. On Little Tombigbee River the same rock makes the celebrated bluffs at Bluffport and at Jones Bluff (Epes), beyond which for several miles it is shown along the stream.

Judging from the width of its outcrop, this division of the Selma chalk must be about 300 feet in thickness. It underlies the most fertile and typical "prairie" lands of the South. At intervals throughout this region the limestone rock appears at the surface in what are known as "bald prairies," so named from the fact that on these spots there is no tree growth. The disintegration and leaching out of the limestone leaves a residue of yellowish clay, which accumulates sometimes to a thickness of several feet in low places. This clay is used at the Demopolis plant in the manufacture of cement, and in most localities where suitable limestone is found the clay is present in sufficient quantity to supply the needs of the cement manufacturer.

At the base of this middle division occurs a bed consisting of several ledges of compact, hard, pure limestone, which weathers into curious shapes, and has received the names horse-bone rock and bored rock. This bed, as above mentioned, appears at the top of Hatchs Bluff; also at Arcola Bluff, and between Demopolis and Epes, at Jordans Ferry, and other places. Where it outcrops across the country it makes a ridge easily followed and characterized by the presence on the surface of loose fragments of the limestone.

The lower part of the formation, like the upper, is composed of clayey limestone, in many places being rather a calcerous clay. The color is dark gray to bluish, and in most exposures there is a striping due to alternate bands of lighter-colored, purer limestone. Along Alabama River the strata of this division are seen in the bluffs from Kings Landing up to Selma and beyond. On Warrior River they are seen in the bluffs at Arcola, Hatchs, Millwood, and Erie, in the last-named locality occupying the upper part only of the bluff. On the Tombigbee, the bluffs at Gainesville, Roes, and Kirkpatricks are formed mainly of the rocks of this division, while above Roes, at Jordans, occurs the line of junction with the middle division. Near this line of division a very characteristic feature is seen at many points. About 10 or 15 feet below the hard ledges of pure limestone forming the base of the middle division the dark-colored argillaceous

rock shows a tendency to flake off and weather into caves, sometimes several feet deep and 20 feet or more in length. These holes extend in some places for great distances along the bluffs, as on Alabama River just above Kings Landing, on the Tombigbee below Roes Bluff, and at Jordans Ferry. The outcrop of the argillaceous rocks of this division gives rise to black prairie soils, in which beds of fossil shells, mainly oysters, are common.

It has been suggested that the argillaceous rocks of this and the uppermost division could be mixed with the purer limestone of the middle division in such proportions as to constitute a good cement material. In this case it would be easy to select localities near the junction of the two divisions where both varieties of the rock could be quarried, if not in the same pits, at least in pits closely adjacent. This would do away with the need of adding other clay to the limestone. Localities of this sort would be found along the borders north and south of the belt of outcrop of the white Demopolis rock.

DISTRIBUTION OF SELMA CHALK.

The general characters of the rocks of this formation have been mentioned above, and it remains to give details of the special localities examined, together with analyses of the limestones collected. In making the collections material from the middle division has been generally chosen, since most of the limestone of the formation which contains 75 per cent or more of carbonate of lime is to be found in this division. At the same time specimens of the more argillaceous material, especially of the lower division of the formation, have been taken for comparison and analysis, in order to ascertain whether it will be practicable to provide a cement mixture by using the proper proportions of the purer and more argillaceous materials.

Inasmuch as suitable material for cement manufacture can be had in practically unlimited quantity all along the outcrop of the purer limestone of the middle division, the location of the plants for the manufacture of this product will be determined by other considerations than the quality of the rock. Chief among these will be facilities for transportation, cheapness of fuel, and cost and abundance of labor. Examinations have consequently been confined to those localities which appear to be most favorably situated in these respects, and especially to those localities which are on navigable streams or on north-south railroad lines, or on both.

The first place considered on Tombigbee River is Gainesville, where the limestone, 30 to 40 feet thick, appears on the river bluff beneath a heavy covering of sands and pebbles. A short distance from the river, however, the rock outcrops at the surface and may be quarried without difficulty. Specimens taken from the different parts of the bluff near the ferry show the composition of the limestone here (see

analyses 1, 2, 3, and 4, p. 82). Other specimens are from the Roberts place, 3 miles east of Gàinesville, one of which was taken from the top of a 30-foot bluff, others from the surface 1 mile and 5 miles from the river (analyses 5 and 6).

At Jones Bluff, on the Tombigbee, near Epes station, on the Alabama Great Southern Railroad, white limestone of remarkably uniform composition shows along the river bank for a distance of a mile or so, with an average height of perhaps 60 feet. Here the bare rock forms the surface, so that there would be no overburden to be removed in quarrying. The railroad crosses the river at this locality, which thus has the advantage of both rail and water transportation. From the lower end of this exposure down to Bluffport the white rock is seen at many points—e. g., below Lees Island, Martins Ferry, Braggs, etc. It generally has a capping of 15 to 20 feet of red loam and other loose materials.

Specimens have been analyzed from Epes and Hillmans (analyses 7, 8, and 9, p. 82).

At Bluffport the white rock in places forms a bluff 100 feet or more in height along the right bank of the river for a distance of a mile or more. This is the counterpart of Jones Bluff, above mentioned, and the character of the material is shown by analysis 10, page 82. As at Epes, the rock extends up to the surface, so that quarrying would be attended with little or no difficulty. Below the Bluffport bluffs the easterly course of the river brings it into the territory of the lower strata of the formation, and the white rock does not appear again below Jordans Ferry, except in thin patches at tops of some of the bluffs. The character of the material of these lower beds may be seen from the analyses of specimens taken from Jordans and Belmont and Roes Bluff, Nos. 11, 12, 13, and 14. The two specimens from the last-named locality represent the composition of the prevailing dark-colored argillaceous rock and of the lighter-colored ledges.

At Demopolis there is an important occurrence of the white rock extending along the left bank from a mile above the landing to about 2 miles below, with average height perhaps of 40 or 50 feet. The rock is remarkably uniform in appearance and probably in composition (analysis 30, p. 83). At McDowells the main bluff is on the right bank and the rock is of great purity, as shown by analysis 16. The exposures continue down to Paces Landing, 9 miles below Demopolis, and beyond this the bluffs are much darker in color and striped with lighter bands, characteristic of the strata of the upper part of the formation. Thence down nearly to Moscow occur the exposures of these upper beds.

Above Demopolis at Arcola and Hatchs Bluff the bluish clayey limestones of the Selma division are seen in force, with the lowermost ledges of the middle division—the horse-bone rock—capping them.

Two analyses of these varieties at Hatchs will show well the contrast in their chemical composition (analyses 19 and 20, p. 82).

From Demopolis eastward the line of the Southern Railway is located on the outcrop of this white rock, at least as far as Massillon, where it passes into the territory of the lower or Selma division. Two miles from Demopolis on this road is the cement manufacturing plant of the Alabama Portland Cement Company, with six kilns in place. The quarry is on the opposite side of the railroad track from the kilns, but only a few hundred feet distant. The clay used is residual clay derived from the decomposition of the limestone, and is obtained from the river bank a few yards away. The composition of the rock and of the clay used in the manufacture is shown by analyses 15, 18, 46, 100. A specimen taken from Knoxwood station, between the cement works and Demopolis station, shows similar composition (analysis 17). The analyses given (61, 63, p. 84) show the chemical character of the cement manufactured at Demopolis.

At Van Dorn station the white rock outcrops in the fields over considerable territory, and just east of the station there is a deep cut through it. Analyses from about Van Dorn show sufficiently well the character of the material at these points (analyses 21, 22, 47, 48, 49, 50, 51, 52).

About Uniontown the bare rock is exposed at numerous points, and the advantages of this place for the location of manufacturing plants seem to be very great. Specimens have been taken from the Bradfield and Shields places, west of the town, from the Pitts place east of it, and from a point south of the town along the McKinley road. Other specimens have come from plantations near the road for several miles eastward and the analyses are appended (analyses 23, 24, 25, 26).

The composition of the residual clay overlying the limestone at the Pitts home place is shown by analysis 55. South of Massillon, near the crossing of the Southern and the Louisville and Nashville railroads, in the vicinity of Martins station, the white rock shows in numerous exposures through the fields, making a country somewhat similar to that about Uniontown. At many points the rock has no overburden and is admirably adapted to cheap quarrying. On the banks of Bogue Chitto Creek, near Martins station, on the Milhous place, the rock is exposed in a bluff with a bed of plastic clay overlying, but here it is below a considerable thickness of red loam and sands of the Lafayette formation. The character of the rock at Milhous station, west of Martins, may be seen from analysis 27.

The same rocks make the great bluff of White Bluff, on Alabama River. Specimens were selected from this bluff at two points—one about halfway down the bluff, the other 20 feet lower. Generally there is a capping of the red loam and sands of the Lafayette over the limestone, but near the upper end of the bluff the white rock extends

to the summit, where it has a capping of plastic clay only. The character of the limestone from this locality is shown in analyses 28 and 29.

At Elm Bluff, as has already been shown, the upper and middle divisions of the formation are in contact. At Kings Bluff the middle and lower parts of the formation are in contact. At the other bluffs of the river between Kings Landing and Selma the rock of the lower division is exhibited. No. 31 is an analysis of the material as exposed at Cahaba; No. 53 of the river bluff at the steamboat landing in Selma, and No. 32 at Benton.

To summarize: From Demopolis eastward along the line of the Southern Railway, by Van Dorn, Gallion, Uniontown, Massillon, and thence by Martins and Milhous stations to White Bluff, the white or Demopolis type of rock appears at the surface in clean exposures at almost innumerable points, either immediately on the railroad or at a very short distance from it. So far as the quality, quantity, and accessibility of the limestone are concerned, manufactories of cement might be located almost anywhere in this territory. From Demopolis westward the same conditions prevail up the river to Epes, and thence to Gainesville, beyond which point the white rock is to the west of the river at greater or less distance.

East of Alabama River the outcrop of the cement rock is crossed by the Louisville and Nashville Railroad (Repton branch), as before stated, between Berlin and Pleasant Hill stations. At Benton, on Alabama River and on the railroad, the limestone has the composition shown by analysis 32.

On the Montgomery and Selma road, at the crossing of Pintlala Creek near Manack station, the limestone is exposed in the creek banks and in the open fields, often with little or no overburden. On page 83 is given an analysis of a specimen from the fields along the wagon road (No. 33) and from the creek bank (No. 34).

On the main branch of the Louisville and Nashville Railroad the white rock shows between the city and McGhees switch, and an analysis of a specimen from McGhees is given (No. 35).

Examinations have not been carried beyond Montgomery, but it is known that the white prairie rock is crossed by the Central of Georgia Railroad between Matthews and Fitzpatrick stations, and there seems to be no doubt that along this stretch of the road suitable rock will be found convenient to the line.

ST. STEPHENS OR VICKSBURG LIMESTONE.

GENERAL DESCRIPTION.

The St. Stephens or White limestone formation of the Alabama Tertiary, which includes the uppermost of the Eocene strata, is in general equivalent to the Vicksburg and Jackson limestones of the Mississippi geologists.

In Alabama St. Stephens exhibits three rather well-defined phases,

which, in descending order, are (1) the Upper or Salt Mountain division, observed at one locality only in Clarke County, (2) the Middle or St. Stephens division, and (3) the Lower or Jackson division. Of these it is only the St. Stephens limestone with which we are here concerned, since the first is, as far as known, restricted to one locality, and the third is seldom exposed along Alabama rivers and railroads.

The following section of St. Stephens Bluff, Tombigbee River, will give an idea of the strata of this division:

Section of St. Stephens Bluff.

	Feet.
1. Red residual clay	1 to 5
2. Highly fossiliferous limestone hold ingmainly oysters, and full of holes, due to unequal weathering	10 to 12
3. Orbitoides limestone (chimney rock), a soft, nearly uniform porous limestone, making smooth perpendicular face of the bluff except where bands of harder limestone of very nearly similar composition alternate with the softer rock. Both varieties hold great numbers of the circular shells of *Orbitoides mantelli*. These harder ledges are nearly pure carbonate of lime, take a good polish, and are often burned for lime	60
4. Immediately below 3, for 5 or 6 feet, the strata were not visible, being hidden by the rock falling from above, but the space seems to be occupied by a bluish clay. Then follows a soft rock somewhat of same consistency as No. 3 above, but containing a good deal of greensand. The fossils are mostly oysters and *Plagiostoma dumosa*. This bed is in places rather indurated superficially, and forms projecting ledges	10 to 15
5. Bluish clayey marl with much greensand, containing the same fossils as No. 4. It washes or caves out from under No. 4, which overhangs it	4 to 5
6. Massive joint clay, yellow on exposed surface, blue when freshly broken; no fossils observed. Extends below the water level to unknown depth; exposed	3 to 4

The rock of this formation, which seems to be the best suited for cement material, is the soft "chimney rock" or Orbitoides limestone of bed No. 3 above. This is usually quarried for chimneys and other constructions by sawing it out and dressing it down with a plane into blocks of suitable size, which are then laid like brick.

The numerous analyses given below will show that this rock is a purer limestone than most of the material of the Selma chalk of the Cretaceous formation above considered. In cement making it will, in consequence, require a larger proportion of clay to be mixed with it, and the question of obtaining suitable clay in sufficient quantity and in close proximity becomes one of some importance. The residual clay left after decomposition and leaching of the limestone seems to be fairly well adapted to the purpose. Besides this residual clay some analyses have been made of the clays of the river and creek bottoms of the country near the limestone outcrops, and of the clays of the Grand Gulf formation, which very generally in this section overlies the limestone. Some analyses of the last-named clays have been made from material occurring near St. Stephens, and near Manistee Junc-

tion on the Repton Branch of the Louisville and Nashville Railroad. At this last-named locality the clay is present in sufficient quantity to be of value if the composition is suitable.

DISTRIBUTION OF ST. STEPHENS LIMESTONE.

The bluff at St. Stephens, a section of which has been given, is typical of the formation everywhere. Here the whole of the soft orbitoidal limestone or "chimney rock" might be used, as the composition is uniform throughout. The overlying harder limestone has almost the same composition, but it is less easily crushed and worked. It may be quarried here from the surface down, as it is covered only by a thin layer of residual clay. The characters of the limestone and of the clay from here are sufficiently well shown by the subjoined analyses (36, 56). The character of the clay near St. Stephens at the water level (No. 6 of the St. Stephens section) is shown in analysis 60. Below St. Stephens there is deep water to Mobile, with the exception of one bar, which may be removed without much trouble or expense.

From Hobson's quarry, just above the Lower Salt Works Landing, down to Oven Bluff, a distance of 2 miles, the Orbitoides limestone or chimney rock occurs at the base of bluffs of Tertiary age.

At the quarry the hard limestone, which is being taken up for riprap work, lies, as at St. Stephens, just above the soft chimney rock. Along the stretch of river above described this chimney rock is seen in a bed 15 or 20 feet in thickness, just above the river bottom, and is easily accessible. As regards clay, three varieties have been examined, a residual clay from over the limestone, a swamp-bottom clay from the low grounds of Leatherwood Creek, and clay from strata of the Grand Gulf formation, which here overlies the St. Stephens limestone. The analyses of these clays have not yet been made.

The first shoal in the river above Mobile is a few miles above Oven Bluff, so that from this place down there is a 9-foot channel at all seasons, which will give to Oven Bluff a certain advantage over other localities in regard to transportation. The shoal mentioned is one which can be removed, so that St. Stephens may be classed with Oven Bluff as regards transportation by water, except that the former is some miles farther from the Gulf than the latter.

Analyses by Doctor Mallett of other specimens of this chimney rock are given on page 83. No. 43 is a clay from Colonel Darrington's place, in the lower part of Clarke County, near Gainestown, and 44 and 45 are from other localities in Clarke County near the rivers.

At Glendon station, a few miles east of Jackson, there is an exposure of the chimney rock close to the track. The rock here is about 20 feet thick, and the limestone is covered by a bed of red residual clay similar to that at St. Stephens and Oven Bluff. The same chimney rock may be seen along the road between the station and Jackson, and no doubt it occurs from Glendon up to Suggsville station, within conven-

ient reach of the railroad. Near Suggsville station the same rock occurs within a short distance of the railroad along the road leading from the station to the town.

Between Suggsville and Gosport the country rock is the St. Stephens limestone, but no particular attention was given to it for the reason that there is no railroad in this vicinity.

At Perdue Hill the St. Stephens rock outcrops near the base of the hills which descend to the terrace on which the town of Claiborne stands. The bluff at Claiborne Landing shows near the summit the calcareous clays or clayey limestone which lies at the base of the St. Stephens formation, and which is generally thought to be the equivalent of the Jackson group of the Mississippi geologists. It is possible that this rock, where it occurs in sufficient quantity, may be suitable for cement making, since its composition is not very different from much of the Rotten limestone or Selma chalk. No investigations have yet been made concerning it, for the reason that there are comparatively few points where it appears in adequate thickness and in favorable localities as regards transportation.

At Marshalls Landing, just above the mouth of Randons Creek, is the first exposure of the chimney rock along Alabama River. This occurs at the top of the bluff. It has the usual covering of residual clay. Below the orbitoidal or chimney rock at Marshalls there are 20 feet or more of a porous limestone. In the same bluff there are beds of calcareous clay, which might possibly be used in mixing with the limestone. At the landing these would be difficult to quarry because of overlying strata, but they would certainly be found without cover along the bluffs above Marshalls if they should prove of value.

From Marshalls down to Gainestown Landing the river bluffs show beds of the limestone at numerous points. At Gainestown, the topmost bed of the St. Stephens, the hard crystalline limestone occurs not far above the water level in the river. This stone has been cut and polished, and proves to be a first-rate marble, inasmuch as it takes a good polish and shows agreeable variations in color. The soft chimney rock underlies the hard limestone here as at other points.

At Choctaw Bluff, some miles below Gainestown, there is the last exposure of the Tertiary limestones on this river. The material is an argillaceous limestone with numerous fossils, but it seems hardly likely to be of use in cement making.

A few miles east of Marshalls Landing, at Manistee Mills, the terminus of a sawmill road, there is a quarry of the chimney rock which is conveniently situated as to transportation, since it is on the railroad. Across the county to the Repton Branch of the Louisville and Nashville Railroad the St. Stephens limestone may, of course, be found at thousands of places, but no mention is made of these occurrences where they do not lie on a railroad line.

Below Monroe station, near Drewry, on the Repton Branch, this road crosses the line of outcrop of the chimney rock, which at a number of points in the vicinity of Drewry lies within easy reach of transportation.

A few miles below Drewry, at Manistee Junction, there is a fine exposure of Grand Gulf clays in railroad cuts both north and south of the station.

Analysis is given (No. 59, p. 84) of the clays from three horizons in these cuts, from which their suitability for admixture with the limestone may be determined.

The chimney rock may be found at many points below Evergreen, in the vicinity of Sparta and Castleberry stations. There are many bluffs of this rock on the banks of Murder Creek in this vicinity, and there are several quarries from which the stone has been obtained for building purposes within short distances of the railroad line. At the foot of Taliaferros Heights the limestone forms high bluffs on the creek, at Ellis Williams Spring there are bluffs with the soft rock at the base and the hard horse-bone rock at the top, and on the creek bank a few hundred yards away is one of the quarries mentioned above. In fact, the localities where the rock may be found within convenient distance of the railroad and in a position favorable to cheap quarrying are numerous in all this region. No clays were seen except the usual residual clays from the decomposition of the limestone and a clay occurring close to Evergreen in the pits of Wild Brothers. Analyses 40, 41, and 42 will show sufficiently well the character of the limestone in this section.

These Evergreen occurrences have attracted attention because of their location on the line of a great railroad system within short distance of tide water.

Farther east this limestone formation extends across Alabama and into Georgia and Florida, but as there is no north-south railroad east of the Louisville and Nashville at this time, the investigations have gone no further.

To summarize: While the St. Stephens limestone outcrops across the State from the Mississippi line to the Chattahoochee River, often occupying broad belts, attention has been concentrated on those localities which lie upon navigable streams or upon railroad lines terminating in Gulf ports. As compared with the middle division of the Selma chalk, this limestone is more uniform in composition, higher in lime content, softer and more easily quarried and crushed, and in geographical position many miles nearer the Gulf. Its thickness, on the other hand, is much less, although sufficient to supply an indefinite number of cement plants with raw material for cement.

ANALYSES.

Analyses of Cretaceous and Tertiary limestones.

Locality.	Insoluble matter.	Iron oxide and alumina (Fe_2O_3 and Al_2O_3).	Lime carbonate ($CaCO_3$).	Magnesium carbonate ($MgCO_3$).	Sulphuric trioxide (SO_3).	Total sulphur.	Water and organic matter.	Alkalies.	Total.
1. Gainesville Bluff, Tombigbee River, 5 feet from top of bluff; R. S. Hodges, analyst	29.50	5.00	56.71	1.69	1.32	......	5.78	......	......
2. Gainesville Bluff, Tombigbee River, lower part of bluff; R. S. Hodges, analyist	23.00	3.14	67.67	2.26	1.97	......	1.96	......	......
3. Gainesville limestone; F. P. Dewey, analyst	18.42	10.79	65.21	1.57	.30	0.83	......	......	97.12
4. Gainesville limestone; A. W. Dow, analyst	27.25	15.96	54.00	1.11	.44	1.23	......	......	99.99
5. Roberts's place, near Gainesville, top of bluff; R. S. Hodges	19.10	3.70	75.57	1.24	.69	......	1.70	......	......
6. Roberts's place, near Gainesville, 5 feet above water; R. S. Hodges	21.98	4.10	69.75	1.50	1.02	......	1.65	......	......
7. Jones Bluff, at Epes; R. S. Hodges	9.44	1.76	86.28	1.02	......	......	1.30	......	100.00
8. Jones Bluff, at Epes; Doctor Mallett	16.69	2.22	80.48	.53	......	......	......	......	99.92
9. Hillmans Bluff, below Epes; R. S. Hodges	16.41	3.14	77.43	1.30	......	......	1.99	......	100.27
10. Bluffport Ferry, Tombigbee River; R. S. Hodges	11.68	1.82	85.10	1.25	......	......	......	......	99.85
11. Jordans Ferry, Tombigbee River; R. S. Hodges	26.26	3.06	67.28	1.87	......	......	1.53	......	100.00
12. Belmont Bluff, Tombigbee River; R. S. Hodges	31.16	5.44	55.84	2.12	......	......	5.44	......	100.00
13. Roes Bluff, Tombigbee River, main part of bluff; R. S. Hodges	31.74	4.42	55.82	2.10	......	......	5.92	......	100.00
14. Roes Bluff, Tombigbee River, light-colored ledges; R. S. Hodges	14.92	3.46	78.52	1.02	......	......	2.08	......	100.00
15. Demopolis, F. P. Dewey; U. S. Mint analyst	13.32	8.74	73.94	1.40	.27	.64	......	......	98.31
16. McDowells Bluff, below Demopolis; R. S. Hodges	6.06	1.62	90.40	1.15	......	......	.77	......	100.00
17. Knoxwood, near Demopolis; R. S. Hodges	15.18	2.22	78.57	1.38	.91	......	1.74	......	100.00
18. Material used in Demopolis Cement Works; R. S. Hodges, analyst	12.50	2.76	80.71	1.05	1.62	......	1.36	......	100.00
19. Hatchs Bluff, Warrior River above Demopolis; main part of bluff; R. S. Hodges	41.18	4.16	44.78	2.68	......	......	7.20	......	100.00
20. Hatchs Bluff; Warrior River, above Demopolis; ledges at top of bluff; R. S. Hodges	3.02	1.10	93.52	1.38	......	......	.98	......	100.00
21. At Van Dorn station, from roadside; R. S. Hodges	14.36	2.80	80.47	1.30	......	......	1.07	......	100.00
22. At Van Dorn station, railroad cut east of station; R. S. Hodges	15.63	2.02	78.77	1.04	......	......	2.54	......	100.00
23. Uniontown, P. H. Pitts, Home place; R. S. Hodges	16.18	3.08	75.35	1.35	......	......	4.04	......	100.00
24. Uniontown, P. H. Pitts, Houston place; R. S. Hodges	19.20	3.58	72.21	1.98	......	......	3.03	......	100.00
25. Uniontown, P. H. Pitts, Rural Hill place; R. S. Hodges	18.62	3.28	74.52	1.17	......	......	2.41	......	100.00
26. Uniontown, 1 mile south, on McKinley road; R. S. Hodges	12.14	......	83.45	......	......	......	......	......	......
27. Railroad cut, Milhous station, Southern Railway, Dallas County; R. S. Hodges	15.30	2.44	80.10	.98	......	......	1.18	......	100.00

Analyses of Cretaceous and Tertiary limestones—Continued.

Locality.	Insoluble matter.	Iron oxide and alumina (Fe_2O_3 and Al_2O_3).	Lime carbonate (Ca CO_3).	Magnesium carbonate ($MgCO_3$).	Sulphuric trioxide (SO_3).	Total sulphur.	Water and organic matter.	Alkalies.	Total.
28. White Bluff, Alabama River; lower part of bluff; R. S. Hodges	26.14	2.78	64.25	......	......	......	......	......	......
30. Demopolis, Tombigbee River; Doctor Mallett, analyst	21.81	2.23	75.07	0.72	......	......	......	......	99.83
31. Limestone from Cahaba, Alabama River; Doctor Mallett, analyst	31.04	2.94	64.37	.79	......	......	......	......	99.14
32. Limestone from Benton, Alabama River; W. B. Phillips, analyst	19.74	11.67	54.83	5.14	0.85	......	4.96	2.88	100.07
33. Limestone from Manack station, Lowndes County; R. S. Hodges.	20.90	4.06	67.16	1.08	1.01	......	5.79	......	100.00
34. Limestone from Manack station; B. B. Ross, analyst	13.20	9.00	74.26	1.46	......	......	......	......	......
36. St. Stephens orbitoidal limestone, St. Stephens, Tombigbee River; R. S. Hodges, analyst	3.38	1.04	92.85	1.92	.13	......	......	......	99.32
41. St. Stephens orbitoidal limestone, near Evergreen; Dr. W. B. Phillips, analyst	1.26	1.72	95.15	.65	.02	......	.65	.11	99.56
42. St. Stephens orbitoidal limestone, near Evergreen; Dr. W. B. Phillips, analyst	2.75	2.73	93.30	.23	.02	......	.60	.14	99.77
43. St. Stephens orbitoidal limestone, Colonel Darrington's, near Oven Bluff, Clarke County; Doctor Mallett, analyst	1.69	2.12	94.84	.96	......	......	......	......	99.61
44. St. Stephens orbitoidal limestone, Clarke County, near river; Doctor Mallett, analyst	2.44	.27	94.85	......	......	......	......	......	99.13
45. St. Stephens orbitoidal limestone, Clarke County, near river; Doctor Mallett, analyst	4.15	1.29	93.19	1.09	......	......	......	......	99.72
46. Rock used in Alabama Portland Cement Works, Demopolis; analysis sent in by T. G. Cairns, general manager	9.88	6.20	77.12	1.08	......	......	5.72	......	100.00
47. Limestone from property of J. B. Kornegay, at Van Dorn, sample No. 1; R. S. Hodges, analyst	16.74	2.09	77.88	.92	......	......	2.37	......	100.00
48. Limestone from property of J. B. Kornegay, at Van Dorn, sample No. 2; R. S. Hodges, analyst.	13.19	2.12	81.89	1.03	......	......	1.77	......	100.00
49. Limestone from property of J. B. Kornegay, at Van Dorn; sample No. 3; R. S. Hodges, analyst.	20.01	2.93	73.64	1.01	......	......	2.41	......	100.00
50. Limestone from property of J. T. Collins, at Van Dorn, sample No. 1; dark color; R. S. Hodges, analyst	16.92	2.94	75.60	1.78	1.10	......	1.66	......	100.00
51. Limestone from property of J. T. Collins, at Van Dorn, sample No. 2; light color; R. S. Hodges, analyst	11.44	1.50	82.61	1.51	.90	......	2.04	......	100.00
52. Average of three samples of limestone from near Van Dorn; L. H. Conard, Demopolis; R. S. Hodges, analyst	16.04	2.46	81.84	......	......	......	......	......	100.34
53. Limestone from bluff at steamboat landing, Selma; T. W. Miller, analyst	16.11	11.22	65.08	2.42	1.40	......	3.37	......	99.65

Clay (Cretaceous and Tertiary) and cement analyses.

Number of analysis.	Silica.	Alumina and iron oxide (Al_2O_3 and Fe_2O_3).	Lime (CaO).	Magnesia (MgO).	Sulphuric trioxide (SO_3).	Sulphur (total).	Ignition.	Total.
55. Residual clay over limestone at P. H. Pitts's home place, Uniontown; R. S. Hodges, analyst	69.57	19.04	0.37	......	......	......	9.68	98.66
56. Residual clay over St. Stephens limestone, St. Stephens Bluff; R. S. Hodges, analyst	59.71	24.79	.48	......	......	......	14.96	99.94
59. Grand Gulf clay, Manistee Junction, Monroe County; T. W. Miller, analyst; average of bed	66.60	25.86	.34	0.34	0.89	......	5.11	99.14
60. Clay at water's edge, St. Stephens Bluff; R. S. Hodges, analyst	49.23	24.42	......	......	......	......	......	......
61. Cement, manufactured by Alabama Portland Cement Co., Demopolis; A. W. Dow, United States inspector of asphalts and cements, analyst	20.25	13.44	63.60	1.03	.41	0.99	......	99.72
62. Cement manufactured by Alabama Portland Cement Co., Demopolis; analysis from T. G. Cairns, general manager	19.99	13.74	61.36	.61	......	......	......	......
63. Cement manufactured by Alabama Portland Cement Co., Demopolis; R. S. Hodges, analyst	19.99	13.63	63.82	.83	1.16	......	......	99.35
64. Residual clay overlying orbitoidal limestone, Marshalls Landing; R. S. Hodges, analyst	51.30	33.22	1.37	.96	.41	......	9.42	97.68

PORTLAND-CEMENT INDUSTRY IN ALABAMA.

In the preceding section Doctor Smith has given a very detailed account of the character and distribution of the cement materials of Alabama. It will be noted that these Alabama deposits, particularly the chalk beds of the Cretaceous, possess many economic advantages over most of the limestones which occur near the Atlantic seaboard. These may be briefly stated as follows:

(1) The Selma chalk deposits of the Cretaceous are in general of almost exactly proper composition for the manufacture of Portland cement, requiring the addition of little or no clay. This correctness of composition will materially reduce the cost of manufacture. The St. Stephens limestone of the Eocene is not so near to ideal composition as the Selma chalk, but will still prove to be a very satisfactory cement material when used in combination with the overlying Grand Gulf clays.

(2) As shown on the accompanying map, coal of good quality occurs within a reasonable distance of the cement beds. As the coal used in boilers and kilns will amount to 60 to 70 per cent of the weight of cement produced, a supply of fuel at low prices is an important element in the success of a cement plant.

(3) Labor is abundant and cheap in the Alabama cement district.

(4) In addition to the local market for cement furnished by such cities as Atlanta, Birmingham, Mobile, and New Orleans, cement plants located upon the navigable rivers of Alabama will be enabled to place their product at any point on the Gulf or southern Atlantic seaboard at very low prices, owing to the cheapness of transportation by water as compared with the railroad freight rates which most other plants will be compelled to pay.

In view of these advantages it seems reasonable to expect that in the near future Alabama will take high rank among the States as a producer of Portland cement. At present, however, only one plant is in operation. This is operated by the Alabama Portland Cement Company, and is located about 1 mile east of Demopolis, Marengo County, on the line of the Southern Railway Company.

The raw materials used are the soft chalky limestone of the Cretaceous and a residual clay, both occurring in the immediate vicinity of the plant. Analyses 1 and 2 of the following table show the composition of the limestone actually used at the plant, while analyses 3 and 4 are from near-by localities. It will be noted that the limestone actually quarried runs only a little too high in lime carbonate to make a good Portland cement by itself. A small amount of clay is added to reduce the lime to a proper percentage. No analyses of this clay are at present available.

Analyses of limestone from Demopolis, Ala.

	1	2	3	4
Silica (SiO_2)	12.50	9.88	12.13	13.32
Alumina (Al_2O_3)	2.76	6.20	4.17	8.74
Iron oxide (Fe_2O_3)			3.28	
Lime carbonate ($CaCO_3$)	80.71	77.12	75.07	73.94
Magnesium carbonate ($MgCO_3$)	1.05	1.08	.92	1.40
Sulphur trioxide (SO_3)	1.62	n. d.	n. d.	.27
Total sulphur (S)	n. d.	n. d.	n. d.	.64
Water	1.36	5.72	n. d.	n. d.

1. Quarry Alabama Portland Cement Company. R. S. Hodges, analyst.
2. Quarry Alabama Portland Cement Company. Sen. Doc. No. 19, 58th Congress, 1st session, p. 22.
3. Demopolis. Proc. Alabama Industrial and Scientific Soc., vol. 5, p. 44-51.
4. Demopolis. F. P. Dewey, analyst.

The following analyses are of the "Red Diamond" brand of Portland cement, manufactured at this plant:

Analyses of Portland cement from Demopolis, Ala.

	1	2	3	4	5
Silica (SiO_2)	20.54	20.25	19.99	19.91	19.56
Alumina (Al_2O_3)	8.55	13.44	13.74	13.63	12.16
Iron oxide (Fe_2O_3)	3.84				
Lime (CaO)	63.85	63.60	61.36	63.82	62.27
Magnesia (MgO)	.66	1.03	.61	.83	.64
Sulphur trioxide (SO_3)	n.d.	.41	n.d.	1.16	.54
Total sulphur (S)	n.d.	.99	n.d.	n.d.	n.d.
Water, etc	1.34	n.d.	n.d.	n.d.	n.d.

1. Clinker. F. W. Clarke, analyst.
2. Cement. A. W. Dow, analyst.
3. Cement. Sen. Doc. No. 19, 58th Congress, 1st session, p. 23.
4. Cement. R. S. Hodges, analyst.
5. Cement. Cement Directory, 2d edition, p. 254.

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SMITH, E. A., and RICO, H. Preliminary report on the clays of Alabama. Bull. Alabama Geol. Survey No. 6, 220 pp. 1900.

PORTLAND-CEMENT RESOURCES OF ARIZONA.

PORTLAND CEMENT MATERIALS.

Little detailed information is obtainable concerning either the areal distribution or the character of Arizona limestones. The few analyses of cement materials available, such as those given in the tables below, have been made in the course of examination of isolated districts.

The following analyses of limestones from the Bisbee district of southeastern Arizona are taken from Prof. Paper U. S. Geol. Survey No. 21, p. 52. The analyses were made by W. F. Hillebrand of specimens collected by F. L. Ransome.

Analyses of limestones from Bisbee district, Arizona.

	1	2	3	4	5
Silica (SiO_2)	11.80	12.53	8.52	0.06	2.52
Alumina (Al_2O_3)	2.15	1.04	.64	.12	.24
Iron oxide (Fe_2O_3)	1.08	1.26			
Lime (CaO)	45.86	27.28	50.07	55.80	53.68
Magnesia (MgO)	.48	17.41	.55	.13	.46

1. Abrigo formation, Cambrian.
2. Abrigo formation, Cambrian.
3. Martin formation, Devonian.
4. Escabrosa formation, Mississippian.
5. Naco formation, Pennsylvanian.

Though the Portland-cement industry has not been established in Arizona, it seems probable that a cement plant, operated by a Government bureau, will be started there during 1905. This interesting experiment is due to the necessity for procuring large supplies of cement, at a low price, for one of the largest of the projected irrigation dams, to be located in the Salt River Valley.

A number of raw materials occurring near the dam site were analyzed, and the results are given in the following table. Of the analyses there quoted, Nos. 1 and 2 represent the limestone and Nos. 6 and 7 the clay which is to be used at the cement plant. The composition of the limestone seems very good; that of the clay is less satisfactory, and it will probably be difficult to obtain a slow-setting cement from it.

Analyses of limestones and shales from Tonto dam site, Arizona.

	1	2	3	4	5	6	7	8
Silica (SiO_2)	3.30	0.51	50.60	55.70	51.00	51.90	50.51	67.90
Alumina (Al_2O_3)	.20	.20	15.80	20.50	16.70	23.70	14.63	18.00
Iron oxide (Fe_2O_3)							5.03	
Lime (CaO)	53.65	55.56	9.30	6.61	3.39	6.10	6.77	......
Magnesia (MgO)	.60	.10	4.07	......	4.58	.97	3.00	.97
Alkalies (K_2O, Na_2O)	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	5.24	n. d.
Carbon dioxide (CO_2)	n. d.	43.77	n. d.	n. d.	n. d.	n. d.	13.30	n. d.
Water	......	......	2.80	11.25	20.10	13.40		.....

1. Limestone near dam site. E. Duryee, analyst. Water Supply Paper No. 73, U. S. G. S., p. 48.
2. Limestone near dam site. U. S. Geol. Survey Laboratory, analyst. Ibid., p. 49.
3. Shale near dam site. E. Duryee, analyst. Ibid., p. 48.
4. Clay 1 mile from dam site. E. Duryee, analyst. Ibid.
5. Clay from Sallie May Canyon. E. Duryee, analyst. Ibid.
6. Clay 3 miles north of dam site. E. Duryee, analyst. Ibid.
7. Clay 3 miles north of dam site. U. S. Geol. Survey Laboratory, analyst. Ibid., p. 49.
8. Shale from canyon below dam site. E. Duryee, analyst. Ibid., p. 48.

A number of samples of limestone from various points along or near Gila River, near projected dams for irrigation purposes, were examined by Mr. E. Duryee, with a view to determining their value as Portland-cement materials. These analyses are given in the following table:

Analyses of limestone near Gila River, Arizona.

[E. Duryee, analyst.]

	1	2	3	4	5
Silica (SiO_2)	1.4	3.7	4.7	4.1	34.6
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	1.3	6.0	1.4	5.8	1.3
Lime carbonate ($CaCO_3$)	96.65	55.92	93.10	90.10	55.50
Magnesium carbonate ($MgCO_3$)		31.00			
Water	.65	1.00			

1. San Carlos, gray.
2. San Carlos, pink.
3. Riverside, blue.
4. Queen Creek, blue.
5. Queen Creek, gray.

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PORTLAND-CEMENT RESOURCES OF ARKANSAS.[a]

PORTLAND-CEMENT MATERIALS.

A number of limestone formations occur in Arkansas, six of which seem to be worth considering as possible sources of cement materials. The limestones which will be described are the following:

	Geologic age.
Izard limestone	Ordovician
Polk Bayou limestone	Ordovician
St. Clair limestone	Silurian
Boone limestones	Mississippian (Lower Carboniferous)
Pitkin or Archimedes limestone	Mississippian (Lower Carboniferous)
White Cliffs chalk	Cretaceous
Saratoga chalk	Cretaceous

[a] The Silurian and Carboniferous limestones are discussed by T. C. Hopkins in a report on the marbles and other limestones of Arkansas, published as Vol. IV of the Report Arkansas Geol. Survey for 1890. The Cretaceous chalks, as later noted, have been described in detail by J. A. Taff, in a report issued by the U. S. Geol. Survey. The descriptions of Arkansas limestones given in the following pages are abstracted from the two reports named. Mr. E. O. Ulrich has kindly furnished many data concerning the Paleozoic limestones.

Southeast of a line drawn through Pocahontas, Powhatan, Jacksonport, Searcy, Little Rock, Benton, Arkadelphia, Prescott, and Texarkana, Ark., is covered by clays and gravels, and so contains absolutely no materials for cement manufacture. All the limestones listed occur northwest of the above line.

This distribution of cement materials is unfortunate, because plants working the Arkansas limestones will be brought into direct competition with Kansas plants using natural gas for fuel, and also because there is no good local market for cement in that part of Arkansas in which the cement materials occur.

IZARD LIMESTONE.

DISTRIBUTION.

The Izard limestone occurs in Independence, Izard, Stone, Searcy, Marion, and Newton counties. It is found in quantity on all the main branches of Lafferty Creek, and ranging in thickness up to 200 feet. In a few places it occurs in almost perpendicular bluffs, but more commonly in steep, terraced slopes. The finest exposures are along the tributary flowing west from Cushman, known as Blowing Cave Creek; in the ravine in the north part of sec. 13, T. 14 N., R. 8 W., and on the lower part of West Lafferty Creek for 4 miles above its junction with East Lafferty. In secs. 3 and 10, T. 14 N., R. 8 W., are areas especially noteworthy both for the quantity and quality of the Izard limestone exposed.

At Penters Bluff on White River and in the adjoining region this limestone is in admirable position for quarrying. Penters Bluff is almost perpendicular and is more than 400 feet high, 285 feet of the base being Izard limestone. In the rear of the lower end of the bluff is a ravine from a fourth to half a mile in length, which penetrates the hill in a direction but slightly divergent from the course of the river, leaving a high narrow wall, which has an abrupt face riverward and is so close to the river bank that there is scarcely room for the road along its base. The rear of this wall is a steep, terraced slope facing the ravine. The south end of the wall is tolerably abrupt for 60 to 70 feet from the base, above which the slope is gentler, and one can with a little difficult climbing at the start ascend to the highest point of the bluff by traversing it lengthwise. The rocks have a low dip to the southeast. The south end of the bluff for about a fourth of a mile consists entirely of the Izard limestone.

West of Penters Bluff, on the north side of White River, the limestone is covered in a few places by the chert débris, outcropping almost continuously along the hills next to the river and on the lower course of all its tributaries as far, at least, as Mount Olive.

The largest and most conspicuous outcrop of Izard limestone west of Penters Bluff is on Wilson Creek in the northwestern part of the

Batesville quadrangle. At the base of the hill on each side of the creek are from 100 to 200 feet of Izard limestone. The bottom of the bed is not exposed. At some places the limestone outcrops in solid continuous layers, while at others the surface is covered with more or less regular rectangular blocks, the result of weathering. The position of the stone for quarrying is all that could be desired.

In the eastern part of Stone County the Izard limestone is extensively developed along the south side of White River. Along the river from a point opposite Penters Bluff to the lower end of Round Bottom this limestone forms the base of the hills for a distance of 100 to 200 feet. Up the river from Round Bottom the base of the hills is composed of the saccharoidal sandstone, the Izard limestone lying near the top. Northward the Izard limestone gradually approaches the tops of the hills, until it thins out and disappears entirely in the northern part of the county, being replaced by the underlying rocks. It is exposed in large quantities along Cagen and Dry creeks, Rocky Bayou, Hell Creek, and South Sylamore Creek, and in smaller quantities on North Sylamore and Livingstone creeks.

In Searcy County the Izard limestone is not nearly so thick as farther east, as it gradually thins to the west. It occurs in considerable quantities along Big Spring, Bald Knob, Little Rock, Rock, Brush, and Bear creeks, on the south side of Buffalo River, and on the north side of Mill and Jimisons creeks.

In the eastern part of Newton County a small quantity of Izard limestone occurs along Buffalo River, the most western outcrop noted being in sec. 26, T. 16 N., R. 21 W., about 1 mile below Jaspar.

THICKNESS OF IZARD LIMESTONE.

The Izard limestone has its maximum thickness on White River at Penters Bluff, Izard County. Here 285 feet are exposed, and the bed extends below the level of the river, so that the total thickness can not be ascertained. From this point it gradually thins eastward to R. 4 W., in Independence County, and westward to R. 18 W., near the western border of Searcy County. It thus has an east-west extent of more than 80 miles. The limits of its exposure north and south vary from 3 to 10 miles, depending upon the topography. At Rocky Bayou its thickness is 160 feet; at Roasting Ear Creek, 150 feet; at St. Joe, 150 feet; on Jimisons Creek, southwest from St. Joe, 50 feet; at Penters Bluff, the lowest exposure on White River, it is 285 feet, while in sec. 26, T. 15 N., R. 10 W., opposite the lower end of Round Bottom, it is 130 feet. The limestone extends much farther up the river and ends somewhere between the mouth of Livingstone Creek and Rappied Branch. On the east end of the river bluff, above the mouth of Hidden Creek, the limestone is 250 feet thick.

DESCRIPTION OF THE IZARD LIMESTONE.

The Izard limestone is a smooth, fine-grained, compact, homogeneous, nonfossiliferous, even bedded limestone, breaking with a conchoidal fracture. It is mostly of a dark-blue color, varying locally to buff, light and dark gray, and almost black.

Partial analyses of Izard limestone.

	From Polk Bayou.	Lithographic quarry, Lefferty Creek.
Insoluble in hydrochloric acid	1.44	0.34
Carbonate of lime ($CaCO_3$)	97.97	98.67
Carbonate of magnesia ($MgCO_3$)	....	2.14
Total	99.41	101.15

POLK BAYOU AND ST. CLAIR LIMESTONES.

DISTRIBUTION.

On the north side of White River these limestones outcrop over a somewhat irregular belt 80 miles or more in length and from 2 to 10 miles in width, running across the central part of North Arkansas in a nearly east-west direction, and extending from Hickory Valley in R. 5 W., to Mount Hersey in R. 19 W., with isolated outcrops as far west as Jasper, in R. 21 W. In Independence County, at the eastern end of the area, the outcrop is all on the north side of White River. It crosses White River at Penters Bluff, from which place it is found only on the south side of the river. Its northwestern boundary in the main is the fault near St. Joe.

In the western part of its area the bed is comparatively thin, its maximum thickness being exposed at Penters Bluff. The western and northwestern limits of the bed are fairly well defined. On the south it dips beneath the overlying Mississippian beds of the Boston Mountains.

On the south side of White River, as on the north side, the marble outcrops along the narrow, winding watercourses. On both sides of the river the rocks have a gentle south dip, so that as the northern limit of the bed is approached the limestone bed occurs higher and higher up the hillsides until it is finally displaced by the underlying Ordovician rocks. On the south side of the river the limestone gradually descends to the beds of the streams, where it dips away gently toward the south, disappearing beneath the overlying Mississippian rocks. Except where concealed by the chert débris, the limestone outcrop on the south side of the river is continuous as far west at least as R. 12.

The eastern limit of the limestone outcrop on the south side of White River is in the NW. ¼ sec. 5, T. 14 N., R. 8 W., just above Penters Bluff. Opposite the bluff the limestone horizon is concealed by chert débris. Upstream from the outcrop in sec. 5 the hills become steeper, and are so close to the river that from Penters Bluff to the mouth of Sylamore Creek they form a river bluff, which is broken by numerous small creeks and ravines and by two short strips of alluvium—Jones Bottom, in R. 9 W., and Round Bottom, in R. 10 W. This bluff is not so high nor so prominent as Penters Bluff, but it consists of the same rocks—Izard limestone at the base, overlain by Polk Bayou limestone, which is capped with chert.

STRATIGRAPHIC POSITION OF POLK BAYOU AND ST. CLAIR LIMESTONES.

Stratigraphic position.—The St. Clair limestone and Polk Bayou formations, considered together, form one of the thickest and most important beds of limestone in the State. They are underlain by the blue Izard limestone and overlain by the Sylamore sandstone (Devonian) or the Chattanooga shale, one or both of which are generally present, often in an inconspicuous bed only a few inches in thickness. In the absence of both the Sylamore sandstone and the Chattanooga shale the St. Clair-Polk Bayou limestones are overlain by the St. Joe limestone, which forms the base of the Boone formation.

THICKNESS OF THE ST. CLAIR-POLK BAYOU LIMESTONES.

The maximum thickness, which is 155 feet or more, is at Penters Bluff, on White River. The limestone thins out gradually toward the east, west, and north; on Polk Bayou it is probably not more than 100 feet thick, while on Dota Creek, still farther east near the Paleozoic border, it does not occur at all. Above the mouth of Hidden Creek, on White river, it is 50 feet thick; but a few miles farther up the river, below the mouth of Twin Creek, there is only a trace of it. On the south side of White River, on Little Rocky Bayou, its thickness is from 25 to 40 feet; on South Sylamore it is from 25 to 50 feet, and at St. Joe it is from 20 to 30 feet.

DESCRIPTION.

In general both the Polk Bayou and the St. Clair limestones are highly crystalline, being composed of small crystals of nearly uniform size. They are tenacious, easily cut, break with difficulty, and have a slightly conchoidal fracture. In weathering, the crystals are separated, resembling coarse sand.

These formations commonly outcrop in heavy layers from 2 to 4 feet or more in thickness; but in some places the rock is massive, the entire exposure being in one solid bed.

Except where deeply stained with manganese and iron the St. Clair limestone is a remarkably pure carbonate of lime.

Analyses of St. Clair and Polk Bayou limestones.

	Brooks mine.	Hell Creek.	St. Joe.	St. Clair Springs.	Lower Polk Bayou.
Silica (SiO_2)	0.73	0.32	0.11	0.54	0.69
Iron oxide (Fe_2O_3)	.11	.30	.08	.19	.27
Alumina (Al_2O_3)	.24	.10	....	.18	.10
Lime (CaO)	54.82	55.74	56.22	54.70	55.21
Magnesia (MgO)	.24	Trace.	Trace.		.27
Potash (K_2O)	.01	.17	.07	.78	Trace.
Soda (Na_2O)	.48	.22	.08		....
Loss on ignition (CO_2, etc.)	43.08	43.31	43.79	43.35	43.39
Total	99.86	100.65	100.31	100.00	100.28
Water at 110°-115°	.09	.059	.04	.04	....
Carbonate of lime ($CaCO_3$)	97.88	98.40	99.68	97.77	98.42

ST. JOE LIMESTONE.

DISTRIBUTION.

St. Joe marble is the name given by the Arkansas geologists to the prominent bed of red limestone which is widely distributed over nearly all the counties of Arkansas north of the Boston Mountains. It is so named from the village of St. Joe, in Searcy County, Ark., where there is a typical exposure and where it was first studied by the Arkansas geological survey. In the publications of the United States Geological Survey this bed is termed the St. Joe limestone member of the Boone formation.

GEOLOGIC POSITION.

The St. Joe limestone is situated at the base of the Boone chert, of which it forms a part. It is underlain by the Chattanooga shale (Eureka shale in part of Arkansas survey) where that formation occurs, otherwise by the Sylamore sandstone or by Silurian or Ordovician rocks. In the eastern part of the marble area of the State it overlies the St. Clair limestone, from which it is separated in most places by a thin bed of Devonian shale or sandstone; west and north of the borders of the St. Clair limestone it overlies the St. Peter saccharoidal sandstone or the Yellville limestone, with either of which in some places, in the absence of the Chattanooga shale, it may be in direct contact.

THICKNESS.

The thickness of the St. Joe bed throughout the greater part of the area in which it occurs is from 25 to 40 feet. But as there is in many places no definite line of demarcation between the marble and the overlying chert, the upper limit of the marble is somewhat arbitrary. In some places in the eastern part of the area the chert rests directly on the Ordovician rocks, showing the entire absence of the St. Joe, while at other places, as at one place in the vicinity of Marble City, the chert is 100 feet and at another it is 250 feet above the bottom of the marble. In such cases, however, the upper part of the bed is of gray limestone similar to that interbedded with the chert elsewhere, but no sharp line can be drawn between the red marble at the base and the gray limestone overlying it, for the two gradually merge into each other.

COMPOSITION.

The chemical analyses given in the accompanying table show the St. Joe limestone to be a comparatively pure carbonate of lime.

Analyses of St. Joe limestone.

	Marble City.	Rhodes Mill.	Tomahawk Creek.	St. Joe crinoidal.
Residue insoluble in hydrochloric acid	0.800	0.835	3.03	1.16
Titanic oxide (TiO_2)	Trace.	Trace.	....	....
Phosphoric acid (P_2O_5)	.023	.009	....	....
Alumina (Al_2O_3)	.009	.024	.18	....
Ferric oxide (Fe_2O_3)	.051	.058	.70	....
Manganese oxide (MnO_2)	.015	.071	....	....
Zinc oxide (ZnO) present, but not determined	....	....	....	....
Potash (K_2O) and soda (Na_2O)	.054	.005	.32	....
Magnesia (MgO)	.190	*.160	.46	....
Lime (CaO)	55.390	55.340	53.46	....
Loss on ignition (CO_2)	43.740	43.630	42.30	....
Total	100.272	100.177	100.38	....
Carbonate of lime	98.91	98.82	95.46	98.73

LIMESTONES OF THE BOONE CHERT.

The Boone chert contains large quantities of limestone, some of the most valuable beds in the State occurring in it. In different parts of the region it varies widely both in quantity and quality. In some places it is made up almost entirely of limestone, while in others it consists almost entirely of chert. For convenience the subject is divided into three parts: (1) The limestone underlying the chert; (2) the

limestone overlying the chert; and (3) the limestone in the chert bed. The bed underlying the chert has been designated the St. Joe limestone and has been described in detail on the preceding pages (93–94).

LIMESTONE OVERLYING THE CHERT BED.

Description.—The limestone overlying the chert bed is classed as part of the chert bed, but in many places it is apparently a separate bed. In most places it is dark gray on a fresh fracture, but on exposure the color changes to a light gray on account of the loss of bituminous matter. In some places the rock is almost entirely free from organic matter. It is coarsely crystalline, slightly fossiliferous, homogeneous in texture, and very tenacious; has a conchoidal fracture, gives out a fetid odor on a fresh surface, and rarely presents sharp edges on weathered exposures, but outcrops in rounded bowlders or prominences through the soil. In places the limestone contains numerous small fragments of angular chert.

Distribution.—The limestone overlying the chert bed was not observed in the eastern part of northwestern Arkansas where, however, limestone does occur in many places near the top of the chert bed, but either contains intercalated chert or is overlain by thin layers of chert, and is distinct lithologically from the bed overlying the chert in the western part of the area.[a] It occurs in the western part of the State, in Carroll, Madison, Benton, and Washington counties, where it outcrops around the numerous outliers of the Boston Mountains. Comparatively small quantities of it are exposed on Grindstone and Pond mountains, near Eureka Springs, but on Swain Mountain, T. 19 N., R. 26 W., it forms a prominent ledge around the east end of the mountain between the chert and the overlying Batesville sandstone, outcropping in rounded ledges along the Eureka Springs-Huntsville road, where it is very dark, almost black, on a fresh surface. It is exposed in large quantities in Stanley Branch around the borders of the Batesville sandstone areas, in heavy ledges around the base of Keefer Mountain south of Hindsville, about Goshen, in T. 17 N., R. 28 W., on the tributaries of Richland Creek, and on Poor, Ellis, Humphrey, Blansett, and other mountains on the west side of White River.

LIMESTONES IN THE BOONE CHERT.

Description.—Though most variable in quantity and quality, the limestones in the Boone chert form some of the largest and most valuable beds in North Arkansas. Instead of a persistent, clearly defined bed of limestone running through the chert, there is rather a bed of chert, with large quantities of limestone variously mixed through it. In some places the limestone occurs in irregular layers, varying from

[a] Mr. E. O. Ulrich states that part of this limestone—the black variety—is a bed in the basal part of the Fayetteville shale.

1 inch to a foot or more in thickness, intercalated with like irregular layers of chert; in other places it occurs in lenticular masses; again, the chert occurs in lenticular or nodular masses in the limestone; in still others the chert and limestone are so intimately diffused that it is not possible to draw any sharp line between them. It often happens, however, that the limestone forms a bed from 20 to 100 feet or more in thickness, almost or entirely free from chert. It is in such places that the stone acquires an economic value. The variability of the Boone formation is largely due to local causes favoring or retarding replacement of limestone by chert.

Nearly all the limestone in the chert is more or less crystalline, but it is much more so in some places than in others. In a general way it is more crystalline in the central part of the area than either to the east or west, and more crystalline in the east than in the west. While there are many local changes in color, texture, and structure of the limestone in the chert, there are some distinctly marked varieties of it.

Distribution.—The oolitic limestone, which is one of the most valuable varieties, is known to occur at three localities: Northeast of Batesville; near War Eagle Creek, about 4 miles north of Huntsville; and on Brush Creek, in T. 17 N., R. 28 W. The rock at Batesville[a] occurs in layers from 3 to 5 feet thick, and can be quarried in as large pieces as can be handled. In color and appearance it resembles the Indiana oolitic stone somewhat, but is harder and more crystalline than most of the Indiana stone and is harder to work. The stone found at the two other localities mentioned above is lighter colored, softer, and more easily wrought.

Another variety occurring in the western part of Independence County is a hard, compact, close-grained, finely crystalline, slightly fossiliferous, dark-colored stone, the dark color being due to bituminous matter, which in some places occurs only in such small quantities as to give the stone a light-gray color. In some places it develops a shaly structure, but in most places occurs in layers from 2 inches to 3 feet in thickness, which are firm, solid, and resonant.

A variety which is widely distributed over the central part of the area is highly fossiliferous, coarsely crystalline, and varies from light to dark gray in color. The fossils are mostly crinoid stems, though the rock contains numerous bryozoans and brachiopods. In some places it contains considerable amorphous matter, but in many places is almost completely crystalline.

Composition.—The limestones in the chert vary greatly in composition, ranging by close gradations from chert to almost pure calcium carbonate. However, in nearly all places where the large beds of

[a] According to Mr. E. O. Ulrich this rock overlies the Boone and belongs to the Moorefield shale.

limestone occur it is comparatively pure carbonate of lime. Some nodules or lenticular masses of chert occur in the heavy beds of limestone, but in no instance was there any considerable quantity of silica found diffused through the bed of limestone. The whole series, in fact, might be divided into (1) chert almost free from lime, (2) calcareous chert or siliceous limestone, and (3) comparatively pure limestone.

Analyses of limestones from the Boone chert.

	1	2	3
Lime (CaO)	55.17	55.42	56.14
Magnesia (MgO)	Trace.	.39	Trace.
Silica (SiO_2)	1.61	.68	.30
Alumina (Al_2O_3)	.00	.00	.00
Iron oxide (Fe_2O_3)	.14	.32	.06
Potash (K_2O)	.14	.19	.12
Soda (Na_2O)	.09	.19	.08
Phosphoric acid (P_2O_5)	.10	.17	Trace.
Loss on ignition, CO_2 and organic matter	43.13	43.56	43.77
Total	100.38	100.92	100.47
Water at 100°-115° C	.057	.09	.49
Carbonate of lime ($CaCO_3$)	98.29	98.59	100.23

1. Allen's quarry, Polk Bayou, sec. 4, T. 13 N., R. 6 W.
2. Near Victor post-office, sec. 10, T. 13 N., R. 7 W.
3. Mill Creek, sec. 13, T. 16 N., R. 18 W.

Partial analyses of limestone from the Boone chert.

	1	2	3	4	5	6	7
Lime (CaO)	54.92	53.66	55.06	54.89	55.09	56.15	55.12
Insoluble (silica)	1.47	4.38	......	......	.50	.19	.28
Magnesia (MgO)	......	......	.03	.21	......	......	.45
Loss on ignition (CO_2, etc.)	......	......	......	......	43.61	43.58	......
Total	56.39	58.04	55.09	55.10	99.20	99.92	55.85
Water at 110-115° C	.10	.31	......	......	.03	......	......
Calcium carbonate ($CaCO_3$)	98.07	95.82	98.32	98.02	98.37	100.25	98.43
Magnesium carbonate ($MgCO_3$)	......	......	......	......	......	......	.95

1. Loster's spring.
2. Jones quarry.
3. Pond Mountain, sec. 23, T. 20 N., R. 26 W.
4. Limekiln at Rogers.
5. Brush Creek, Madison County, sec. 25, T. 17 N., R. 28 W.
6. Sec. 15, T. 17 N., R. 26 W.
7. Denieville, Independence County.

PITKIN OR ARCHIMEDES LIMESTONE.

DESCRIPTION.

The Pitkin or Archimedes limestone is impure, generally loose textured, and very fossiliferous, varying from bluish gray to brown in color. In most places it is distinguished by its characteristic fossil, a spiral-shaped bryozoan of the genus *Archimedes*, from which its former name was derived. The compactness of the stone appears to vary with the size of the fossils. When they are large the texture is open, being often but a loosely aggregated mass; when the fossil fragments are small they are closely compacted and the rock is firm and durable. In some places the formation graduates into sandstone, the change being so gradual that there is no line of demarcation between the two. In other places it is very argillaceous, and in most places contains iron and bituminous matter. In some places it has a loose, shaly structure, while in others it occurs in strata 10 feet or more in thickness.

THICKNESS.

The Pitkin or Archimedes limestone varies in thickness from a few inches to 80 feet or more. Its thickness is from 25 to 40 feet in Washington County, 80 feet on Pinnacle Mountain, Newton County, and apparently more than this on the face of the Boston Mountains, south of Buffalo River, where no measurement was made. Mr. C. E. Siebenthal reports a thickness of 200 feet in the Boston Mountains, south of Mountain View.

DISTRIBUTION.

This limestone is widely distributed over northern Arkansas, occurring at nearly all clear rock exposures at the proper horizon, but as it is in some places less durable than the overlying rocks, it is frequently concealed by talus. In some places it is more durable than the overlying rocks and forms a prominent escarpment along the face of the mountains. It outcrops along the north face of the Boston Mountains and in many of the northern outliers from Independence County west into Indian Territory. It outcrops also on the south side of the Boston Mountains in several places in Crawford, Franklin, Johnson, and Newton counties. In Limestone Valley, Franklin County, it has a thickness of 100 feet or more.

It is prominently developed in the group of mountain peaks in the southern part of Boone County and the northern part of Newton County. At Fodder Stack it forms the cap rock, about 100 square feet. On Pinnacle Mountain it occurs in a prominent ledge 80 feet thick, 400 feet below the top of the mountain. On Pilot Mountain, at the north end of Boat Mountain, it is 30 feet thick and lies 200 feet below the top of the mountain. It is concealed by talus in many places on both Pilot and Boat mountains.

There are large exposures of the Archimedes limestone on both sides of Buffalo River, in Newton County, on the mountain between

Big and Little Buffaloes, and at many places along the north face of the Boston Mountains in Searcy, Stone, and Independence counties. It outcrops prominently on the mountain south of Jamestown, Independence County, as well as at many places on Salado Creek, in the same county, and it skirts the highlands southwest of the Oil Trough bottom.

CRETACEOUS CHALK BEDS.[a]

The Cretaceous rocks of Arkansas occur only in the southwestern portion of the State, reaching as far northeast as Arkadelphia (See Pl. III. On the north they are bordered by Paleozoic sandstones and shales, while on the south and east they pass out of sight beneath a series of sands, gravels, and clays of later age.

In the present discussion the only part of this series to be considered is the chalk formation of the upper Cretaceous. This is geologically continuous with the Texas chalk (see pp. 308–309), but is covered in many places by sands, gravels, and river bottoms, so that it occurs as a series of isolated outcrops. It outcrops near Rocky Comfort, in Little River County, and near White Cliffs, Saline Landing, Washington, and Okolona, and on Big and Little Deciper creeks.

While the chalk of all these areas is of upper Cretaceous age, there is a considerable variation in stratigraphic position. The chalk beds at Rocky Comfort, White Cliffs, and Saline Landing become more sandy and clayey and less chalky as they are traced northeastward from the last-named area, and soon become worthless as cement materials. At the same time a series of limy clays, situated geologically about 200 feet above this first chalk series, becomes more chalky as it is traced northeastward; and this second chalk bed is worth considering as a cement material in its outcrops near Washington and Okolona, and on the Deciper creeks.

The first or lower series of chalk beds has been called the Whitecliffs[a] formation and the second series the Saratoga formation, both being named from localities at which they are well exposed.

The different areas of outcrop will be discussed separately in order from southwest to northeast, after which a large series of analyses of the chalk will be presented.

WHITECLIFFS (ANNONA[b]) FORMATION.

ROCKY COMFORT AREA.

The chalk which outcrops in the vicinity of Rocky Comfort is remarkably uniform in physical appearance. It is massive, white,

[a] The description of the Cretaceous chalks is taken from a very detailed report, by Mr. J. A. Taff, on The chalk of southwestern Arkansas, with notes on its adaptability to the manufacture of hydraulic cements, in Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 3, pp. 689-742. So far as possible this matter is stated in Mr. Taff's own words.

[b] As the term White Cliff had been applied in 1876 to a formation in the Uinta Mountains, the name Annona, from Annona, Red River County, Tex., where the chalk is well exposed, has been adopted for it by the U. S. Geological Survey.

sufficiently friable to soil the fingers, and thin pieces may be broken in the hands, but the hammer is required to pulverize the massive rock. On exposure the chalk breaks into conchoidal fragments, which weather to lumps and finally become chalky dust. In the hillsides south of town the bedding is scarcely preceptible.

The composition of fresh chalk from the bed of the branch at the base of the exposure is given in analysis No. 4 (p. 111), while No. 3 shows that exposed in the ditches, 55 feet higher. The former is not many feet above the base of the true chalk and the latter belongs near the middle. This chalk is in physical appearance like that of Whitecliffs, and a comparison of the analyses shows that this chalk and that from Whitecliffs quarry have practically the same composition.

The lower beds are exposed by the road in the SE. ¼ of SE. ¼ sec. 21, T. 12 S., R. 32 W., also near the middle of sec. 21, with chalky marl cropping below. These basal beds are more clayey and siliceous than those higher in the formation south of Rocky Comfort.

From the center of sec. 21 to the "line road" in the SW. ¼ sec. 29 the chalk is concealed beneath residual black soil. At the latter locality the chalk is well exposed in ditches and on high ground along the road almost through the SE. ¼ of SW. ¼ sec. 29. The lower beds of the formation are also exposed in the hill and bluff facing the river bottom in the NE. ¼ of NE. ¼ sec. 31.

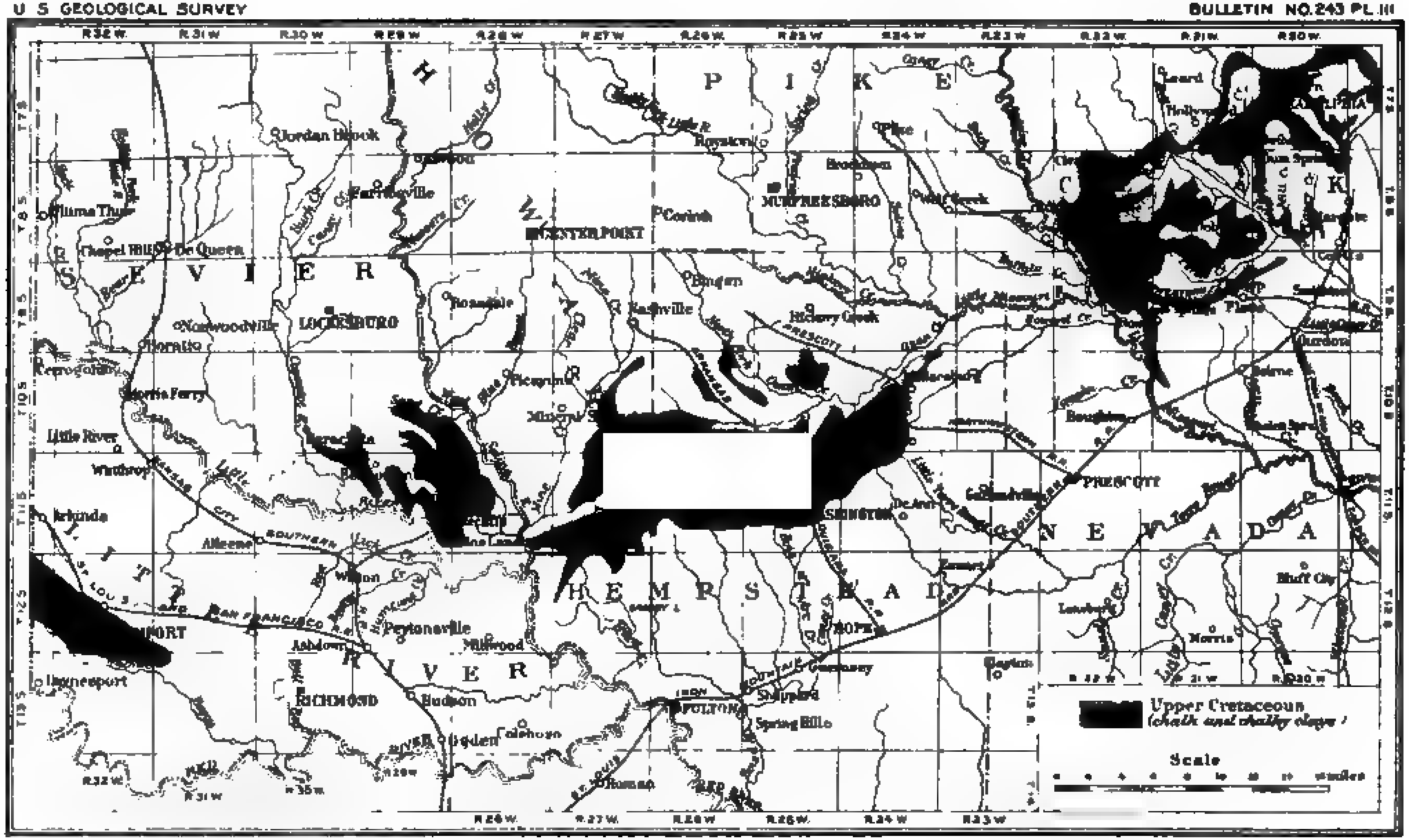
From the base of the chalk downward there is a transition zone of bluish clayey chalk which grades down into still less chalky clay. This transition clay chalk is exposed at the contact in the SW. ¼ sec. 29, and in deep ditches on the hill slopes below the Hopson graveyard, in the NE. ¼ of NE. ¼ sec. 30.

Analysis No. 2 (p. 111) is of a specimen of the transition clayey chalk from the latter locality. While the analysis shows that the marl contains 25 per cent of silica, sand is not visible.

From sec. 30 northward to the Holman place, near the center of sec. 18, the clayey chalk is generally concealed by its residual soil. Grayish-blue, sandy, chalky marl, partially indurated at the surface, outcrops at the Holman House and in gullies 500 feet farther west. This chalky marl is perceptibly more sandy than that higher in the section immediately below the true chalk.

The crumbling edges of the chalk deposits outcrop in the low bluff of Walnut Bayou bottom from the NE. ¼ of NE. ¼ sec. 30 southward to the extreme south end of the chalk area, in the SE. ¼ of SW. ¼ of sec. 32.

Excellent exposures of the chalk occur in and near the road in the SW. ¼ of SW. ¼ of sec. 32. The analysis of this chalk is given in No. 1 of the table. The chief difference between this and the other samples of the purer chalk analyzed is that it contains much more



MAP OF THE CHALK REGION OF SOUTHWESTERN ARKANSAS

BY JOSEPH A TAFF

1904

clay. The only perceptible physical difference, however, is that it is a little harder.

A rather large exposure of white chalk, of beds near the top of the formation, appears on Col. Henry Hawkins's place, in the NW. ¼ sec. 33. About one-fourth mile southeast of the house, in the SE. ¼ of NW. ¼ sec. 33, the top of the true chalk and the base of the succeeding chalky marl is exposed. A thin mantle of gravel conceals part of both the chalk and the marl. The upper layers of the chalk are also exposed south of the branch, in the SE. ¼ sec. 28.

There are smaller exposures of chalk in this region, but it is believed that those above described are typical.

WHITECLIFFS AREA.

The chalk here exposed occupies parts of secs. 25, 26, 35, and 36, T. 11 S., R. 29 W., and secs. 30 and 31, T. 11 S., R. 28 W., and covers an area of about 600 acres.

A large part of the chalk of the Whitecliffs area is covered by a thin mantle of gravel and sand. In places this gravel may attain a thickness of several feet, but it is believed that it will nowhere interfere seriously with the removal of the chalk. The chalk is also concealed in places, especially near the border of the the area, by its own residual soil, with scattered pebbles or a very thin layer of gravel.

The most noteworthy exposure of chalk in southwestern Arkansas occurs in the cliffs overlooking Little River from the east side, in the northeast corner of sec. 35, T. 11 S., R. 29 W., immediately above the ferry.

From the brink of the cliff down to the water level is 115 feet, and about 15 feet of chalk is exposed at a higher level by the road which leads from the cement works. The following is a detailed section, beginning at the top of the chalk and marl in the cliff:

Section at Whitecliffs Landing.

	Feet.
1. Massive, creamy white chalk, in beds from a foot to about 10 feet thick, separated by thin partings of very slightly laminated chalk. The variation in the character of the chalk from bed to bed is not perceptible on physical examination, and the stratification planes are not clearly defined except upon partial weathering of the rock. Analysis No. 7 (p. 111) is of specimens in the lower part of this chalk, while No. 9 is an average of specimens from each bed in the lower half as exposed in the quarry. No. 8 is from about 10 feet below the top as exposed by the road opposite the cliff..........	60
2. Massive dull bluish-white siliceous chalk. Slightly harder than the pure chalk of 1, practically without indication of bedding, and because of its hardness projects in a steep bench overhanging the less chalky beds below. Analysis No. 6 shows that this chalk contains nearly twice as much silica as the chalk above. This bed occurs in the bench beneath the quarry and passes to the level of the river bottom near the clay pit south of the works. An outcrop occurs also near the middle of the bluffs north of the cliffs, spreading out at the surface in the cultivated fields 1 mile southeast of the village of Whitecliffs..............................	25

	Feet.
3. Massive, very siliceous, dull-blue argillaceous chalk marl. This bed contains more than twice as much sand and nearly three times as much clay as the overlying bed No. 2. The rock is quite friable and weathers in recesses beneath the siliceous chalk	8
4. Bluish, sandy, chalky marl, containing great numbers of the fossils shell *Gryphæa vesicularis*. Except for the abundant fossils this rock would be classed with No. 3, though it is probably slightly more sandy	7
5. Bluish, sandy, chalky marl, gradually increasing in sandiness from the top downward to the level of the river	35

The lower 30 to 35 feet of the white chalk of 1 is freshly exposed in the quarry.

The top of the bluish-white chalk of 2 forms the bench beneath the quarry and occurs at the base of the bluff southeast of the landing.

The sandy chalk members 3, 4, and 5 rise gradually northward from the lower part of the cliff and are found in the highland between the villages of Whitecliffs and Brownstown.

One-half mile west of Doctor Coats's house, in the NW. ¼ sec. 23, T. 11 S., R. 29 W., bed No. 4 is exposed at the top of the bluff and below it is the following section, well shown in deep gullies down to the level of the valley:

Section of marl below the Whitecliffs chalk.

	Feet.
1. Sandy, chalky marl. Dull bluish when not weathered, becoming grayish or whitish yellow after long exposure. It contains numerous specimens of the large oyster *Exogyra ponderosa*, besides *Ostrea larva* and many other fossils common to the Upper Cretaceous marls. The upper half of this member is No. 5, at the base of the cliff at Whitecliffs Landing	60
2. Blue clay marl containing some large oysters as above, and less lime than No. 1, and much more clay	30
3. Dark-blue gritty greensand marl with scattering smooth round pebbles of black and white quartz 1 inch and less in diameter	10
4. Blue clay marl down to the level of the bottom land, exposed	15

This section is about 2 miles north-northeast of the chalk cliff which is in the NW. ¼ sec. 35, and the sandy marl bed, which is here about 100 feet above the river, is at the water level at the cliff. This marl bed with the associated marls and chalks above, which are conformable with it, dips toward the southeast at the rate of about 50 feet per mile. The base of the chalk at the north side of the chalk area is fully 50 feet above the river bottom. At the south side, a mile distant, it is at the level of the bottom. There may be local variations in the dip of the beds, but the general dip is estimated to be nearly 50 feet per mile toward the southeast.

SALINE LANDING AREA.

The chalk of this area extends with practically continuous exposure from the chalk bluff at Saline Landing, in the south half of sec. 35, T. 11 S., R. 28 W., to sec. 14, T. 11 S., R. 27 W., and is about 7 miles in

length and one-third of a mile in width. The map of this chalk area is given as Pl. III.

The base of the chalk is not exposed in this area, though the lower sandy member outcrops in secs. 21 and 22, toward the source of Plum Creek. These outcrops occur in the border of the creek bottom, within less than 1 mile of the exposure of fossiliferous blue marl outcropping on the north side of Plum Creek in secs. 15 and 16. The structure of the rocks shows that this marl belongs not more than 50 feet below the base of the chalk.

The chalk at the top, as exposed in many places in the south side of the area, grades up into blue clay marl through 20 to 30 feet of marly chalk and chalky marl. This gradation is especially well shown in the chalky barren hill slopes near the Columbus Mineral Springs road, in the south side of sec. 14, T. 11 S., R. 27 W.

The thickness of the chalk in the southwestern part of the area is not known, as its lower portion is concealed. Near the northeast corner of sec. 22, T. 11 S., R. 27 W., the full thickness of the purer chalk above the lower sandy member will not exceed 25 feet. Near the east side of sec. 14, T. 11 S., R. 27 W., the entire chalk bed passes beneath the bottom of Plum Creek.

The divide between the sources of Plum and South Ozan creeks is flat, and the chalk deposits are entirely concealed beneath the soil. The crop of the chalk, as indicated by the structure of the rocks, would extend northeastward through secs. 7, 8, 5, 4, and 3, in T. 11 S., R. 26 W., and into Ozan Creek bottom. The location of this probable outcrop is shown in Pl. III.

The chalk bluff at Saline Landing is 20 feet in height (above low water) and about 300 feet long. When visited by Mr. Taff the river was at flood, so that less than 10 feet of the rock was exposed to view. The lower portion of the chalk as then exposed is white, massive, and without distinct bedding planes, the upper 5 feet being weathered to a chalky earth. Specimens of the chalk were collected from the water level, which would be near the center of the bluff at the usual low stage of the river. Analysis 10 (p. 111) of this chalk is nearly the same as No. 6, which is of the lower sandy member of the Whitecliffs (Annona) formation, and suggests that the exposure at Saline Landing is in the lower part of the chalk formation in this area.

The chalk has been quarried for building purposes near the top of the formation in the northwest corner of the NE. ¼ of SW. ¼ sec. 30, T. 11 S., R. 27 W. Analysis 11 (p. 111) is of fresh chalk from this quarry, and shows it to be of nearly the same composition as that near the top of the chalk at Whitecliffs.

From the top of the chalk in this vicinity there is a gradual change upward through about 10 feet of marly chalk and then through nearly

30 feet of chalk marl into the overlying blue-clay marl. The blue marl is continuous for 175 feet to the base of the Saratoga chalk marl.

The middle portion of this chalk is exposed in the large mound, which is surrounded by the bottom land of Plum Creek, in the center of the SE. ¼ of SW. ¼ sec. 21, T. 11 S., R. 27 W., on Mr. J. E. Johnson's place. Here also the chalk has been quarried, giving fresh exposures of the rock. Analysis 12 (p. 111) is of fresh chalk taken from this quarry, and is nearly the same as that from the quarry of the Whitecliffs Cement Works.

The lower sandy member of the chalk is freshly exposed in the head of the large drainage ditch near the middle of the west side of the SW. ¼ of NW. ¼ sec. 22, T. 11 S., R. 27 W. Analysis 14 of this chalk is practically the same as No. 6, which is of a specimen from the lower sandy member in the cliff at Whitecliffs Landing.

The upper and purer chalk member is well exposed in the ditches and chalk barrens on the lower ridge across the SW. ¼ of NE. ¼ sec. 22, T. 11 S., R. 27 W.

The easternmost exposure of the chalk south of Plum Creek is in the SE. ¼ sec. 14, T. 11 S., R. 27 W. Here the chalk barrens in the slopes of the hill show the upper edge of the chalk and the succeeding chalk and clay marl for 50 feet above the creek bottom.

SARATOGA FORMATION.

The Saratoga chalk, as explained previously, occurs nearly 200 feet above the Whitecliffs chalk and is separated from it by more clayey beds.

This formation has a maximum thickness of about 50 feet where complete sections have been found. The nature of the deposit varies only slightly from top to bottom, and there is but little change in character along its outcrop from the vicinity of Saratoga near West Saline River, in Hempstead County, to Little Deciper Creek near Arkadelphia, in Clark County. The Saratoga marl is not known in this region west of West Saline River, because of erosion and of concealment by Neocene gravel and sand in the highlands and by Pleistocene alluvium and silt in the lowland and river bottoms.

General section of the Saratoga chalk marl.

	Feet.
1. Continuing upward from 2 the chalky rock becomes more sandy through imperceptible grades to limy greensand at the top of the formation. Analyses from the chalk near the central part of this member show it to contain from 40 to 50 per cent of silica	20–30
2. Generally even-textured chalky marl, which contains less sand than the beds higher in the formation. Chemical analyses of chalk from this bed show it to contain about 31 per cent of siliceous matter. The sand in this marl is perceptibly finer and the rock is more chalky in appearance than in other parts of the formation	10–15

	Feet.
3. Sandy clayey chalk, which contains great numbers of the fossil oyster *Gryphæa vesicularis*. These fossils are found in the marls some distance both above and below this formation, but in no other bed of rock in this region have they been found in such abundance. In natural exposures the chalk weathers from about them so that they usually almost cover the surface of the ground or are scattered in the soil. This shell bed at the base of the formation is such a marked feature that when it is once seen it may be easily recognized again. This shell bed crops at the north border of the Saratoga marl and throughout its extent	3-5

The Saratoga marl is a massive bed of dull-bluish, sandy, chalky rock. Exposures do not usually show distinct bedded structure, though a slight variation in weathered surfaces may indicate the direction of the dip of the rock. As the rock weathers it changes in color from dull blue to shades of grayish and creamy white. Its hardness and general physical appearance are almost identically the same as those of the lower sandy member of the Whitecliffs chalk. It breaks in rudely conchoidal flakes and crumbles at the tap of the hammer. Small pieces of the fresh rock may be broken by the hand and crumbled to dust between the fingers, but not without some difficulty.

WASHINGTON AREA.

The rock section is well exposed, as illustrated in the section.

Section north of Saratoga.

	Feet.
1. From the level of Saratoga down to Saratoga marl, surficial deposit of fine yellow sand, about	40
2. Saratoga chalk exposed in brink of hill north and east of Saratoga and in knob one-half mile north of Saratoga, lower beds of the formation	20
3. Limy blue-clay marl	175
This marl is exposed around the base of the hill at Saratoga, and in the cultivated lands 1½ miles north of the town it becomes gradually more chalky downward from the top to its contact with the chalk marl below.	
4. Bluish friable chalk marl	20-30
This is the gradation bed from the blue marl above into the purer chalk below.	
5. White chalk in the Saline Landing area.	

Thick deposits of sand cap the hill at Saratoga, concealing all of the chalk rock except the lower beds in the slopes east and northeast of the town.

The lower part of the Saratoga chalk outcrops in a considerable area on Mr. Jones's place in the NE. ¼ sec. 35, SW. ¼ sec. 25, and SW. ¼ sec. 36, T. 11 S., R. 27 W. The chalky oyster-shell bed at the base of the formation is well exposed north, south, and west of the house, which is in the NE. ¼ of NE. ¼ sec. 35.

Samples of the chalk were taken from the top of the oyster-shell bed near the base of the formation, and are not physically different

from the same bed examined at other localities in this area. The fresh rock is grayish white and sandy.

The shell bed at the base of the formation is exposed at the edge of the highland near the Columbus-Albrook road, 1 mile northwest of Columbus. The same bed is exposed also at the crest of the highland 1 mile north of the town. The chalk marl highest in the formation occurs in the cultivated fields between the outcrop of the shell bed and the town.

From the vicinity of Columbus eastward to the end of the formation in the Washington area the whole of the Saratoga formation outcrops or is covered only lightly by soil. Throughout this extent the basal shell-bed member of the chalk marl is almost continuously exposed, except in the immediate bases of the valleys, and may be easily located through the open fields by means of the abundant shells weathering upon the surface.

Between Columbus and the railroad north of Washington the chalky marl was not found to outcrop more than 30 feet in thickness, and usually 10 to 20 feet of the lower part was all that was exposed.

The overlying greensand marl is more friable than the Saratoga chalk marls, and its soil descends and conceals the contact between the two as well as the upper part of the latter. A section of the Saratoga marl with better exposures than are usually found occurs along the railroad north of Washington.

The north cut on the railroad is in a blue clay-marl 30 to 50 feet below the base of the Saratoga formation. It is 10 feet deep and about 300 feet long. The marl in this cut, which was originally blue, is weathered a creamy yellow to a depth of about 8 feet. It is transected by many joints, which pass nearly vertically across the bedding and continue down below the base of the cut. Along these joints, even below the zone of general weathering, the blue color of the marl is changed to yellow for a distance of several inches.

Analysis 15, page 111, is of the unchanged blue marl from the base of the cut, 10 feet below the soil. The fresh marl is friable when dry and plastic when wet. It has a very fine texture and contains scarcely perceptible grit, yet the analysis shows it to contain 43 per cent of silica and 6.5 per cent of clay. Nearly 40 per cent of this silica is in the form of impalpable sand.

The shell bed, the base of the Saratoga formation, is exposed in the field southwest of this railroad cut. The middle cut is one-third of a mile south of the north cut and is in the lower part of the Saratoga chalk above the oyster-shell bed. This cut is 300 feet long and but a few feet deep, exposing an estimated thickness of 15 feet of rock. The structure of the rock indicates a low inclination toward the south, but is not sufficiently clear to determine the degree of dip. Ditches above the south end of the cut expose about 25 feet of chalk marl

above that at the railroad, making the whole section of rock exposed at this place nearly 40 feet. Very little change in the nature of the rock could be noted in this section.

Analysis 16 is of the fresh chalk rock near the center of the middle cut, from the lower and more chalky part of the formation, and shows that this marl contains less than one-half the amount of silica found in the blue marl 40 feet below, though in physical appearance it is more sandy.

One-half mile south of the middle cut and a few hundred feet north of the south cut the top of the Saratoga marl is exposed in a ditch at the railroad. The sandy marl in this exposure is but little above the chalky marl at the top of the exposure opposite the middle cut. It is massive, dull blue, and very sandy, approaching a sandstone in composition.

The south cut, which is about 2 miles north of the town of Washington, is in the lower part of the greensand marl which overlies the Saratoga formation. This cut is about 30 feet deep and about 300 feet long. From the surface downward about 20 feet the greensand is weathered from dark blue or greenish blue to shades of dull brownish yellow. Unaltered marl was collected from near the base of the cut, and its composition is shown in analysis 17. Physically it is very sandy, and the analysis shows that it contains 75.77 per cent of silica and 5.72 per cent of lime. Similar greensand marl occurs between this cut and Washington, and its thickness is estimated to be more than 100 feet.

From the railroad eastward to the end of the formation in this area, in sec. 29, T. 10 S., R. 24 W., the Saratoga chalk crops in an irregular belt one-half to three-fourths mile wide, making an intermediate upland, marked by projecting ridges and spurs between the high timbered greensand country on the south and the flat black land of the clay marls bordering Ozan Creek bottom on the north.

OKOLONA AREA.

This area is in the southwestern part of Clark County, south and east of Okolona, between the bottom lands of Antoine and Terre Noire creeks.

The Saratoga chalky beds at the crest of the ridge south of Okolona are 50 to 150 feet above the lowland to the west and south. The crest of this ridge slopes southward with the dip of the rock, which is nearly 50 feet per mile.

East of Okolona the chalky marl forms a triangular area of rolling upland about 3 square miles in extent.

The stream which rises in the southwest part of the town and flows southeastward past the railroad station separates the area south of the town from that east of it. It is probable that these two areas are

connected by narrow bands of outcropping marl which extend down the sides of the valley about 2 miles southeast of the village.

The Saratoga chalk-marl is partially exposed near the crest of the escarpment north of the Okolona-Dobyville road, from the east side of sec. 30, T. 8 S., R. 21 W., to the edge of the Terre Noire bottom, 1½ miles east of Dobyville.

The Saratoga marl, near the middle of the formation, is well exposed toward the top of the ridge at the forks of the road, 1½ miles south of Okolona. In physical appearance this rock is the same as that at the middle of the formation in the vicinity of Washington. It is massive and dull blue on fresh exposure and weathers to shades of drab or light yellow. Analysis 19, page 111, shows that the chalk-marl in this locality contains nearly 43 per cent of silica and 49 per cent of calcium carbonate.

Two and one-half miles south of Okolona and one-fourth of a mile west of the road, on the Mat Hardin place, deep gullies expose the lower 20 feet of the Saratoga marl as well as the blue marl below. The *Gryphæa vesicularis* bed is well marked, but the fossils are a little less abundant than in the Washington area, 20 miles farther west. In the lower 10 feet of the formation the chalk-marl is finer in texture and more chalky than in the higher beds. The result of an analysis of chalk from this place is given as No. 21, page 111, and shows that the amount of silica is nearly 10 per cent less than in the marl near the middle of the formation.

Numerous other exposures of the lower part of the formation occur in the gullies and slopes of the hill on the west side of the ridge, where the land was once cultivated. The top of the Saratoga marl passes beneath the bottom land of Little Missouri River, about 3 miles south of Okolona.

Five miles south of Okolona the greensand marl, which belongs above the Saratoga chalk, forms the bluffs from the level of the Little Missouri bottom up to the top of the ridge. This is the greensand formation which occurs between Washington and the Saratoga chalk in Hempstead County.

About 20 feet of the middle portion of the formation is exposed in the Okolona-Garden road, 1 mile east of Okolona.

In the high rolling country east of Okolona the Saratoga chalk-marl is generally concealed beneath its own soil or beneath sand of Neocene age.

The lower beds of the chalk outcrop in the Okolona-Dobyville road, 2 miles west of Dobyville, and at several other places in the top of the escarpment between Okolona and Dobyville.

One-fourth of a mile north of Joseph Doby's house, at Dobyville, the full section of the Saratoga chalk-marl is exposed in an old field.

Following is a section of Saratoga chalk-marl at Dobyville:

Section at Dobyville.

		Feet.
1.	Gravel, reddish and yellow stratified clays	20
2.	Blue marl	15
3.	Dull-bluish chalky marl	35
	This marl is slightly indurated at the top and contains numerous casts of bivalve shells and gastropods. It is a calcareous sandstone at the top. The beds become more chalky downward, until the lower part of the chalky marl is found to be the same in nature as that described as occurring south of Okolona and in the Washington area.	
4.	Even-textured chalk-marl, with *Gryphæa vesicularis* shells at the base	15
	This member contains more chalk than those above and has finer texture. In places, also, very fine particles of greensand were noted disseminated through the marl.	
5.	Fine-textured blue clay marl.	
	This is the upper part of the 150 to 200 feet of blue marl which lies between the Whitecliffs chalk formation and the Saratoga chalk-marl.	

From the vicinity of Okolona eastward, the outcrop of the Saratoga marl descends gradually from the brink of the escarpment to the level of the river bottom, nearly 2 miles east of Dobyville.

DECIPER AREA.

The next known occurrence of the Saratoga chalk-marl east of Okolona is on Big Deciper and Little Deciper creeks, 3 to 5 miles west of Arkadelphia.

The occurrence of the Saratoga chalk on the Deciper creeks is confined to outcrops in the middle and lower slopes of the valley near the Arkadelphia-Dobyville and Arkadelphia-Hollywood roads. The general location of the outcrop is shown in Pl. III.

Near the center of sec. 28, T. 7 S., R. 20 W., on the Bozeman place, one-third of a mile northeast of the house, about 30 feet of the Saratoga chalk-marl is exposed, as follows:

Section of the Saratoga chalk-marl at the Bozeman place, beginning at the base.

		Feet.
1.	Sandy soil to the top of the ridge.	
2.	Chalky marl, more sandy than that of 3	10–15
	The sandy element in this marl increases in quantity upward.	
3.	Even-textured blue chalk-marl	15
	This clalk contains a sprinkling of fine greensand, and in all respects is the same as the lower 15 feet of the formation at Dobyville and Okolona. Analysis No. 24 shows that this marl contains about 30 per cent of sand and 61 per cent of chalk.	
4.	*Gryphæa vesicularis* shell marl	1–2
	The limits of this shell bed are not sharply marked. Through 1 to 2 feet of the marl at the base the shells are abundant, and in it is a thin layer of shells indurated by calcareous matrix.	
5.	The blue marl from the *Gryphæa vesicularis* shell bed downward; exposed	15

At two points, one of them one-fifth of a mile northeast and the other 500 feet east of the Bozeman house, the chalky marls occur higher in the formation and are still more sandy than that of No. 4 in the section given on page 109. These outcrops are in the heads of narrow gulches which descend to the Deciper Valley. At the locality 500 feet east of the house the marl is very sandy, partially indurated, and contains numerous casts of fossils similar to those found near the top of the formation at Dobyville. The exposures here show about 10 feet of marl and are just below the springs which flow from the base of the stratified yellow sands and blue clays.

About 10 feet of interstratified sand and clay is exposed above the sandy marl, and then follows an overwashed yellow sandy soil to the top of the hill, 40 feet above.

One-fourth of a mile southeast of Mount Bethel Church, near the northeast corner of sec. 33, T. 7 S., R. 20 W., beds similar to those east of the Bozeman house are exposed. Here a spring issues from the contact between the chalk-marl and the overlying sand and blue clay. The top of the marl is 70 feet below the crest of the hill.

The chalky sand of the upper part of the Saratoga formation is exposed on the Arkadelphia-Okolona road, on the west bank of Big Deciper Creek, near the middle of sec. 34, T. 7 S., R. 20 W., as well as in the bluff of the creek near by. The top of the sandy marl, which stands here 20 feet above the creek, contains casts of fossils as at the Bozeman place, and is overlain also by the same kind of interstratified sand and clay.

Twenty feet of the even-textured lower and more chalky member of the Saratoga chalk-marl is exposed in the road cut on the Arkadelphia-Okolona road, 100 yards west of Little Deciper Creek.

Sand and clay conceal the higher beds of the chalk-marl. The *Gryphæa vesicularis* bed, with underlying blue marl, outcrops a few feet above the creek bottom.

One-half mile above the road, on the Wright place, the lower 30 feet of the Saratoga formation is exposed in the gullies at the west side of the creek bottom. The lower 10 to 15 feet of the marl is identically the same as that found at the road and on the Bozeman place west of Big Deciper Creek, as shown in analysis 26, page 111. The basal member of the chalk-marl, containing the same indurated shell bed, outcrops here at about 10 feet above the creek bottom, and below it is the blue marl. Yellow sandy clays overlie the chalky marl here, as in the exposures noted on Big Deciper Creek.

At the east side of the creek bottom, on the Arkadelphia-Okolona road, and northward through the Haskins place, the lower part of the chalk-marl is exposed in gullies in an abandoned field.

ANALYSES.

Analyses of chalk and chalk marl from southwestern Arkansas. [a]

No.	Silica (SiO_2) and insoluble.[b]	Ferric oxide and alumina ($Fe_2O_3+Al_2O_3$).	Lime (CaO).	Magnesia (MgO).	Equal to lime carbonate ($CaCO_3$).	Equal to magnesium carbonate ($MgCO_3$).
1	6.15	5.79	46.81	0.33	83.60	0.69
2	25.13	3.90	35.81	.61	64.32	1.28
3	8.53	1.22	48.50	.38	86.60	.78
4	7.32	1.26	49.94	.32	89.17	.67
5	27.28	5.00	34.81	.61	62.15	1.28
6	12.67	1.93	45.56	.43	81.35	.90
7	6.83	.95	50.41	.22	90.01	.46
8	7.86	1.30	49.55	.28	88.48	.58
9	7.97	1.09	49.64	.35	88.64	.73
10	14.68	2.15	45.03	.44	79.40	.92
11	4.91	.93	51.78	.30	92.46	.63
12	7.35	1.06	49.66	.34	88.67	.71
13	34.76	5.18	29.10	.71	51.95	1.49
14	12.65	1.66	45.85	.49	81.87	1.02
15	43.09	6.55	22.77	.92	40.65	1.93
16	21.90	2.35	40.57	.59	72.41	1.23
17	75.77	5.46	5.72	.91	10.21	1.91
18	30.68	4.91	32.60	.48	58.22	1.00
19	43.72	2.76	27.95	.42	49.90	.88
20	35.16	2.85	32.75	.43	58.48	.90
21	31.05	3.46	32.18	.69	57.41	1.44
22	31.01	2.93	34.63	.50	61.83	1.05
23	36.17	5.37	29.16	.48	52.06	1.00
24	32.26	7.05	17.24	.63	30.78	1.32
25	30.84	3.73	34.31	.60	61.26	1.26
26	30.29	3.31	34.77	.55	62.08	1.15

[a] By chemists of the United States Geological Survey.
[b] "Insoluble" refers to insoluble in HCl. The other columns refer to the soluble portions only.

References to analyses.

Rocky Comfort area.

1. SW. ¼ of SW. ¼ sec. 32, T. 12 S., R. 32 W., 2 miles southwest of Rocky Comfort. White chalk near the middle of the chalk formation.
2. NE. ¼ of NE. ¼ sec. 30, T. 12 S., R. 32 W., 2 miles west of Rocky Comfort. The chalky marl immediately below the white chalk.
3. Rocky Comfort, Little River County, Ark., near the NE. corner of NE. ¼ sec. 28, T. 12 S., R. 32 W., from lower middle part of the white chalk formation.
4. Same locality as 3, from the lower part of the white chalk formation.

Whitecliffs area.

5. NE. ¼ of NE. ¼ sec. 35, T. 11 S., R. 29 W., top of the lower sandy marl bed beneath the white chalk.
6. Chalk bluff, Whitecliffs Landing, near the middle of the bluff in the lower part of the white chalk.
7. Chalk bluff, Whitecliffs Landing, 15 feet above the base of the purer white chalk.
8. Chalk bluff, Whitecliffs Landing. White chalk 10 feet below the top of the cliff.
9. Cement works, Whitecliffs Landing. Average of the lower 35 feet of the purer white chalk in the quarry at the cement works.

Saline Landing area.

10. Saline Landing, Howard County, Ark. Sec. 35, T. 11 S., R. 28 W., from the middle of the chalk bluff.
11. NW. corner of the NE. ¼ of SW. ¼ sec. 30, T. 11 S., R. 27 W. White chalk from very near the top of the chalk formation.
12. Near the center of the SE. ¼ of SW. ¼ sec. 21, T. 11 S., R. 27 W., from near the middle of the white chalk.
13. Near the base of the knob 1 mile N. 15° E. from Saratoga, Ark. Chalky blue marl 100 feet above the top of the white chalk.
14. Near the center of the east side of the SW. ¼ of NW. ¼ sec. 22, T. 11 S., R. 27 W., from the lower part of the white chalk.

Washington area.

15. North cut on the railroad, about 3 miles north of Washington, Ark. Chalky blue marl 40 feet below the base of the Saratoga chalk-marl.
16. Middle cut on the railroad, about 2¼ miles north of Washington, Ark., from the center of the cut in the lower part of the Saratoga chalk-marl.
17. South cut on the railroad, about 2 miles north of Washington, Ark., from the green sand marl in the center of the cut.
18. SE. ¼ sec. 25, T. 10 S., R. 25 W., head of Morisett ditch, from bluish chalky marl, about 150 feet below the Saratoga chalk-marl.

Okolona area.

19. Forks of road, 1¼ miles south of Okolona, Ark., from middle of Saratoga chalk-marl.
20. SE. ¼ sec. 4, T. 9 S., R. 22 W., about ¼ mile southwest of Okolona, from sandy marl bed at base of the Whitecliffs chalk formation.
21. 2¼ miles south of Okolona, on the Mat. Hardin place, from the lower 15 feet of the Saratoga chalk-marl.
22. Same locality as 21. Saratoga chalk-marl 16 feet above the base.
23. SE. ¼ sec. 4, T. 9 S., R. 22 W., about 1¼ miles south of Okolona, yellowish chalky marl about midway between the Whitecliffs and Saratoga formations.

Deciper area.

24. J. L. Bozeman's place, ¼ mile northeast of the house, in the NW. ¼ of sec. 28, T. 7 S., R. 20 W., from the bluish chalky marl 4 feet below the base of the Saratoga chalk-marl.
25. Same locality as 24, from Saratoga chalk-marl 10 feet above the base.
26. Little Deciper Creek at Okolona-Arkadelphia road, from Saratoga chalk-marl about 10 feet above the base.

TERTIARY AND CARBONIFEROUS CLAYS AND SHALES.

The information below on clays is from a publication on Cement Materials of Southwest Arkansas, by Doctor Branner.[a]

In no case are the surface clays found in the immediate vicinity of the chalk deposits to be depended upon. Such clays are, as a rule, too sandy, and are not of uniform composition. Reference is here made especially to the sandy clays overlapping the chalk beds to the north and east of Rocky Comfort, and the clays of the bottom lands south and west of Whitecliffs, and those south, north, and west of the chalk exposures at Saline Landing. Fortunately the Tertiary rocks which overlap the Cretaceous ones to the south and east contain an abundance of excellent clays available for the manufacture of cement. Some of these clay beds are utilized for the manufacture of pottery at Benton and Malvern (Perla switch). There are many other deposits on and near the railway about Arkadelphia, Malvern, between Malvern and Benton, between Benton and Bryant, at Olsens switch, and at Mabelvale. At Little Rock there are extensive beds of both clays and clay shales, while beds of shale may be found along the line of the Little Rock and Fort Smith road to Fort Smith and beyond.

The Tertiary clays at Benton, Bryant, Olsens switch, Mabelvale, and Little Rock are all nearly horizontal beds, dipping gently toward the southeast. They can be had in many places by stripping off a few feet of post-Tertiary gravel and soil; but in places the covering is too thick to be removed, and the clays can be obtained only by a system of drifts.

[a] Trans. Am. Inst. Min. Eng., vol. 27, 1897, pp. 42-63.

LOCATION OF CLAYS.

Only a few of the many known localities are here mentioned. On account of the geographic relations to the chalk beds, only those places convenient to railway transportation along the St. Louis, Iron Mountain and Southern Railway southwest of Little Rock are spoken of in this paper. Should a factory, on account of fuel or for other reasons, be located west of Little Rock, clays derived from the Carboniferous clay shales would have to be used. Of these there is no lack between Little Rock and Fort Smith.

There are two general classes of clays at Little Rock available for cement manufacture: (1) The Tertiary clays that occur in horizontal beds in the southern and southwestern part of the city; and (2) the Carboniferous clay shales exposed in the railway cuts along the south bank of Arkansas River, in the cuts west of the town, and in others west of Argenta.

There are other clays about Little Rock and Argenta, such as the chocolate-colored clays along the margins of the river bottoms, and the pinkish clays forming the high river terraces and used for making bricks on the north side of the river; but these latter two kinds of clays are not available for cement manufacture, partly because they are too sandy, but also because they are not homogeneous. An analysis of the pink clay of Argenta shows it to contain more than 83 per cent of silica.

The Carboniferous clay shales are well exposed in the railway cut near the upper bridge, and where the electric power house stands. Similar shales may be found here and there over a large part of Pulaski County, within the Carboniferous area.

COMPOSITION OF CLAYS.

The following analyses show the composition of the clays. These analyses are of representative samples. Most of them contain some sand, usually quite fine. In those cases in which the percentage of sand is given the analyses are of the washed clay.

Analyses of Carboniferous shales from Arkansas.

	1	2	3	4	5	6	7	8
Silica (SiO_2)	53.30	62.36	58.43	65.12	57.12	55.36	51.30	69.34
Alumina (Al_2O_3)	23.29	25.52	22.50	19.05	24.32	26.96	24.69	22.56
Iron oxide (Fe_2O_3)	9.52	2.16	8.36	7.66	8.21	5.12	10.57	1.41
Lime (CaO)	.36	.51	.32	.34	.72	.30	.32	Trace.
Magnesia (MgO)	1.49	.29	1.14	.31	1.74	1.16	.63	Trace.
Soda (Na_2O)	2.76	.66	1.03	.85	.53	1.03	.72	2.31

Analyses of Carboniferous shales from Arkansas—Continued.

	1	2	3	4	5	6	7	8
Potash (K_2O)	1.36	1.90	2.18	1.23	2.07	2.69	2.18	0.04
Water	5.16	5.32	6.87	6.12	7.58	7.90	9.11	5.12
Total	100.48	98.72	......	......	......	100.52	......	......
Sand in air-dried clay	......	......	......	21.88	......	......	......	......

1. Clay shale from railroad cut at south end of upper bridge, Little Rock.
2. Decayed shale from Iron Mountain railroad cut at crossing of Mount Ida road, Little Rock.
3. Clay shale from Nigger Hill, Fort Smith.
4. From Harding & Boucher's quarry, Fort Smith.
5. Clay shale from Round Mountain, White County, sec. 6, T. 5 N., R. 10 W.
6. From Clarksville, east of college.
7. From SE. ¼ of SW. ¼ sec. 31, T. 10 N., R. 23 W.
8. From NW. ¼ sec. 23, T. 1 N., R. 13 W.

Analyses of Tertiary clays from Arkansas.

	Silica (SiO_2).	Alumina (Al_2O_3).	Iron oxide (Fe_2O_3).	Lime (CaO).	Magnesia (MgO).	Soda (Na_2O).	Potash (K_2O).	Water.	Titanic acid.
1	63.07	23.92	1.94	0.23	Trace.	1.08	1.15	7.07	......
2	72.44	18.97	1.59	.18	Trace.	.91	1.35	5.39	......
3	69.95	22.34	1.44	Trace.	.08	1.18	1.28	5.98	......
4	71.09	19.86	1.81	.11	......	.81	1.45	5.67	......
5	65.27	18.75	7.34	.81	1.26	.81	1.10	6.88	......
6	64.38	17.29	8.25	1.11	.80	.42	1.41	6.95	......
7	63.19	18.76	7.05	.78	1.68	1.50	.21	7.57	......
8	64.49	23.86	2.11	.31	Trace.	1.82	.11	8.11	......
9	67.90	22.07	1.33	.05	.59	.38	1.15	6.86	......
10	48.34	34.58	1.65	.81	Trace.	1.26	.44	12.94	1.56
11	62.34	20.63	3.34	.17	.67	.33	.73	9.34	1.49
12	68.03	17.19	3.00	.81	1.00	.54	1.00	6.31	......
13	63.29	18.19	6.45	.31	2.44	Trace.	.56	......	......
14	76.33	16.04	1.24	By difference, .99				5.40	......
15	75.99	16.12	1.35	By difference, 1.45				......	......
16	73.24	19.61	1.04	By difference, .78				......	......
17	45.28	37.39	1.71	1.83	.29	......	......	13.49	......

1. Benton, Hick's bed, sec. 12, T. 2 S., R. 15 W.
2. Benton, Rodenbaugh, sec. 12, T. 2 S., R. 15 W.
3. Benton, Herrick & Davis's bank.
4. Benton, Henderson's pit, upper bed.
5. Mabelvale, A. W. Norris's well.
6. Olsen's switch, "fuller's clay."
7. "Fuller's earth," Alexander, SW. ¼ SE. ¼ sec. 8, T. 1 S., R. 13 W.
8. Benton, Woolsey's clay.
9. Ridgwood, SW. ¼ NE. ¼ sec. 25, T. 1 N., R. 12 W
10. Benton, Howe's pottery.
11. Clay from sec. 4, T. 8 S., R. 15 W.
12. Clay from sec. 5, T. 8 S., R. 15 W.
13. Clay from S. ½ sec. 13, T. 2 S., R. 13 W.
14. John Foley's, NE. ¼ SE. ¼ sec. 18, T. 13 S., R. 24 W.
15. Climax pottery, W. ½, SE. ¼ sec. 5, T. 15 S., R. 28 W.
16. Atchison's, NE. ¼ NE. ¼ sec. 24, T. 4 S., R. 17 W.
17. Kaolin, sec. 36, T. 1 N., R. 12 W., Tarpley's.

PORTLAND-CEMENT INDUSTRY IN ARKANSAS.

A Portland-cement plant was erected at Whitecliffs Landing, on Little River, 1 mile south of Whitecliffs post-office, and a branch railroad constructed from the river opposite the plant to Wilton, on the Kansas City Southern Railroad, in 1895. On account of litigation between those financially interested the works have been idle since May, 1900. The members of the company and those involved in the litigation were scattered, and it was not practicable to obtain a correct history of operations. Operations were resumed late in 1901, with the name of the company changed to the Southwestern Portland Cement Company.

Four continuous dome kilns were utilized, and the bricks passed upon cars from the forming machine through the drying plants to the elevators, which conducted them to the kilns. From the kilns the clinker returned on cars to the crushing plant and mills.

The quarry in the rear of the works is elevated, so the chalk descends by gravity to the reducing machines. Clay silt from the river bottom land near by was utilized as a mixture with the chalk. The use of this material, because of its convenient location, instead of clays of high grade was a mistake, it is believed.

Coal and coke of high grade in large quantity occur in eastern Indian Territory on or near the Kansas City Southern Railroad. This fuel may be transported by rail at small cost directly to the cement works.

Until the year 1900 the nearest cement plant of any nature to the Whitecliffs works was at San Antonio, Tex., a distance of 375 miles. In this year a Portland-cement plant was erected at Dallas, Tex., where a mixture of upper Cretaceous chalk from the southern extension of the Whitecliffs formation and underlying clay marl is utilized. The product from this plant will naturally supply a large part of the North Texas market at least. The Whitecliffs cement should supply all Arkansas, Indian Territory, central Oklahoma, a large part of Louisiana, and possibly western Tennessee and Mississippi. Transportation north and south is direct by the Kansas City Southern, northeast and southwest by the St. Louis, Iron Mountain and Southern, and east and west by the Choctaw, Oklahoma and Gulf and the Memphis and Choctaw railroads.

The chalk deposits at Rocky Comfort are within 1 mile of the Arkansas and Choctaw Railroad, which connects with the Kansas City Southern at Ashdown. This road is extending westward to tap the Missouri, Kansas and Texas at Ardmore, Ind. T.

The chalk of the Saline Landing area is more than 10 miles by direct line from the St. Louis, Iron Mountain and Southern and the Arkansas and Louisiana railroads. Saline Landing, however, which is upon the chalk, may be accessible to the St. Louis, Iron Mountain and

Southern Railway at Fulton by West Saline River, which is navigable to small steamers during a large part of the year.

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PORTLAND-CEMENT RESOURCES OF CALIFORNIA.[a]

PORTLAND-CEMENT MATERIALS.

Few extensive belts of limestone are found in California, but numerous comparatively small areas occur, and many of them furnish rock suitable for use as a Portland-cement material. Three Portland-cement plants are now in operation, and the prospects seem good for a marked expansion of the California cement industry. Owing to the lack of good native coals and the abundant supply of petroleum, oil is used as fuel.

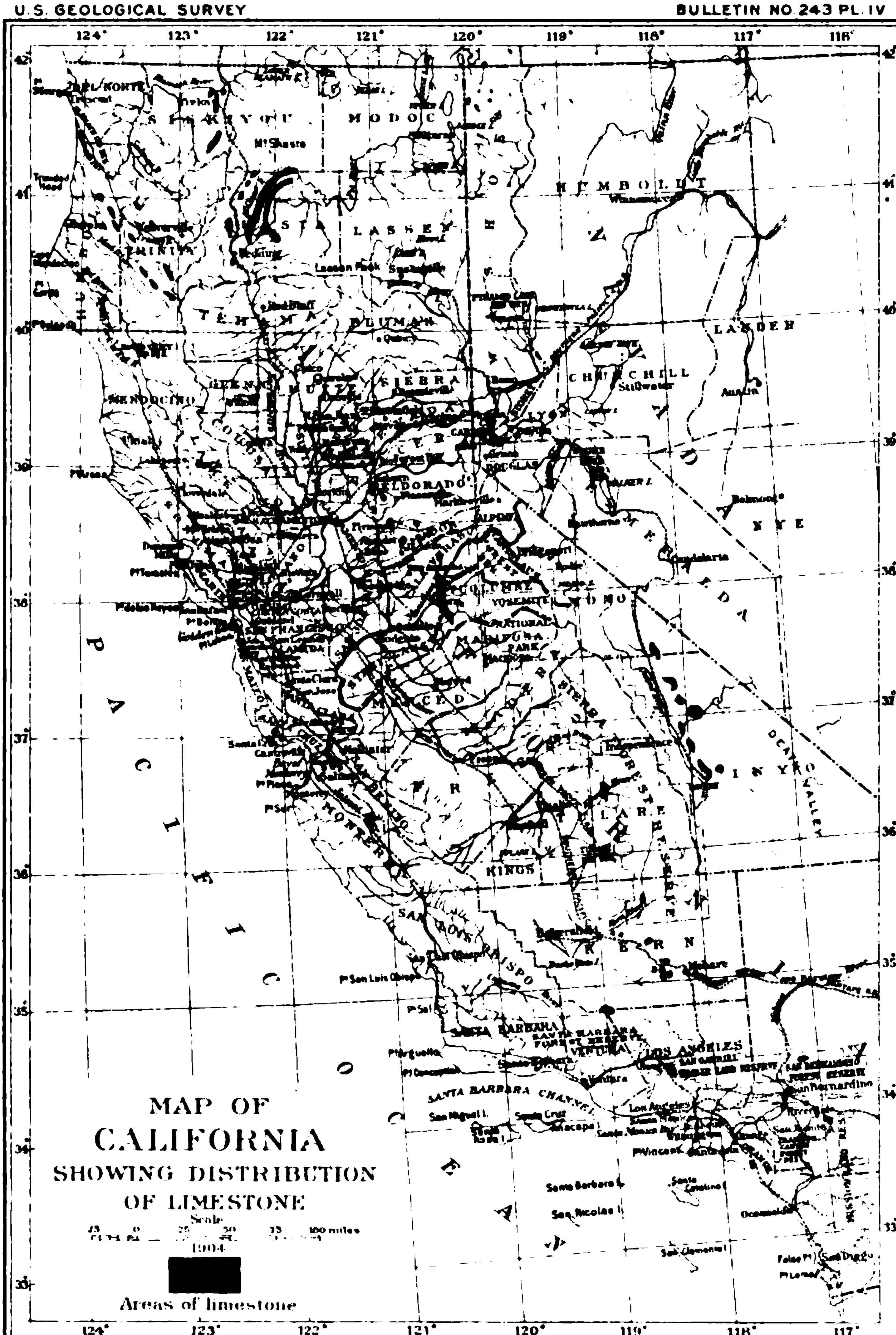
DISTRIBUTION.

Detailed mapping of California geology has been of such a fragmentary character that few generalizations can be made regarding the occurrence of good cement limestones. The areas in which limestones are known to occur are indicated on the accompanying map (Pl. IV), but not all of the areas shown will give material fit for Portland cement; and, on the other hand, deposits of good material probably exist which do not appear on the map. The map will, however, serve as a guide in the location of deposits of available cement materials.

SAN DIEGO COUNTY.

Fine-grained, chalk-like limestone occurs near the coast at Jamul, San Diego County, where it was used about 1888 in a small Portland-cement plant. Its composition is as follows:

[a] Many of the data in this section, when not otherwise credited, have been abstracted from the valuable reports of the State mineralogist of California. The writer is, however, responsible for the discussion of the cement industry and of the different plants, all of which were visited during the fall of 1903. Mr. J. S. Diller, of the United States Geological Survey, has furnished all the data referring to the limestones of the Redding district, and has very kindly located these Shasta County deposits on the accompanying map.


MAP OF
CALIFORNIA
SHOWING DISTRIBUTION
OF LIMESTONE
Scale
1904
Areas of limestone
P A C I F I C
O C E A N
MODOC
LASSEN
TEHAMA
PLUMAS
SIERRA
MENDOCINO
ELDORADO
MARIPOSA
MERCED
MONTEREY
KINGS
KERN
SAN LUIS OBISPO
SANTA BARBARA
LOS ANGELES
VENTURA
INYO
MONO
TULARE
HUMBOLDT
LANDER
CHURCHILL
NYE
SANTA BARBARA CHANNEL
San Nicolas I.
San Clemente I.
Lassen Peak
Mt Shasta
Redding
Austin
Stillwater
Candelaria
Independence
Bakersfield
Mojave
Los Angeles
San Bernardino
Riverside
San Diego
Oceanside
Santa Cruz
Monterey
Yosemite
San Luis Obispo
Pt Sal
Pt Conception
San Miguel I.
Santa Catalina I.
Santa Barbara I.
False Pt
Pt Loma
124° 123° 122° 121° 120° 119° 118° 117° 116°
42° 41° 40° 39° 38° 37° 36° 35° 34° 33°

Analysis of limestone from San Diego County, Cal.[a]

Silica (SiO_2)	1.86
Alumina (Al_2O_3)	1.10
Lime carbonate ($CaCO_3$)	94.28
Magnesium carbonate ($MgCO_3$)	1.19
Alkalies (K_2O, Na_2O)	1.15

ORANGE COUNTY.

In Orange County a shell limestone is exposed at San Fernando, and outcrops on the mesa at various places, both toward Orange, where there is a large exposure at the Los Alisos ranch, and toward San Juan.

Analyses of shell limestone from Orange County, Cal.[b]

	1	2
Silica (SiO_2)	14.25	27.08
Alumina (Al_2O_3)		
Iron oxide (Fe_2O_3)		
Lime carbonate ($CaCO_3$)	81.36	65.26
Magnesium carbonate ($MgCO_3$)	.76	1.22
Alkalies (K_2O, Na_2O)	1.32	2.02
Lime sulphate ($CaSO_4$)	.42	1.02
Water	1.25	1.20

LOS ANGELES COUNTY.

On the flat land at the edge of the foothills near Mission San Fernando, Los Angeles County, a shell limestone of the following composition occurs in extensive deposits:

Analysis of limestone from Los Angeles County, Cal.

Silica (SiO_2)	19.72
Alumina (Al_2O_3)	3.27
Iron oxide (Fe_2O^3)	
Lime carbonate ($CaCO_3$)	72.68
Magnesium carbonate ($MgCO_3$)	1.05
Alkalies (K_2O, Na_2O)	.67
Sulphur trioxide (SO_3)	Trace.
Water	1.76

[a] Ninth Ann. Rept. California State Mineralogist, p. 309.
[b] Eighth Ann. Rept. California State Mineralogist, p. 880.

SAN BENITO COUNTY.

The following partial analyses of very pure limestones occurring west of Hollister, in San Benito County, are given in the Mineral Resources of the United States for 1889–90, page 383:

Analyses of limestones from San Benito County, Cal.

	1	2	3
Silica (SiO_2)	2.10	0.7	0.5
Lime carbonate ($CaCO_3$)	96.00	99.2	99.0

SANTA CRUZ REGION.

Extensive deposits of a soft, chalk-like limestone occur near Santa Cruz. These deposits are accompanied by shales and clays of good composition, as can be seen from the following analyses:[a]

Analyses of cement materials from Santa Cruz, Cal.

	Limestone.		Clay.		
Silica (SiO_2)	2.40	4.71	63.73	60.03	62.22
Alumina (Al_2O_3)	.51	1.20	22.12	21.76	20.02
Iron oxide (Fe_2O_3)	.56	.60	9.01	11.49	8.25
Lime (CaO)	51.31	50.02	2.83	3.37	1.96
Magnesia (MgO)	1.25	.75	Trace.	.25	Trace.
Alkalies (K_2O, Na_2O)	1.45	1.80	.21	1.36	.81
Carbon dioxide (CO_2)	40.32	39.25	n. d.	n. d.	n. d.
Water	1.21	1.40	1.12	1.45	6.52

[a] Eighth Ann. Rept. California State Mineralogist, p. 881.

SOLANO AND CONTRA COSTA COUNTIES.

Beds of soft limestone, usually quite high in clayey matter, are exposed from Vallejo to Goodyears, Solano County, and from Mount Diablo to Pinole, Contra Costa County.

Analyses of limestones from Solano and Contra Costa counties, Cal.[a]

	1	2	3	4	5
Silica (SiO_2)	9.05	42.61	12.89		0.26
Alumina (Al_2O_3)	7.56	15.05	....	6.12	.20
Iron oxide (Fe_2O_3)	5.20	4.10	2.95		....
Lime (CaO)	33.35	17.98	40.32	50.85	54.80
Magnesia (MgO)	1.25	2.60	2.26	.24	.30
Alkalies (K_2O, Na_2O)	2.05	.26	.37	.83	.14
Sulphur trioxide (SO_3)	1.03	.84	....	n. d.	n. d.
Carbon dioxide (CO_2)	28.56	14.12	40.11	41.96	43.38
Water	2.05	.96	.67	n. d.	.50

1, 2, 3. Contra Costa County, between Mount Diablo and Pinole.
4. Benicia, Solano County.
5. Port Costa, Contra Costa County.

SONOMA COUNTY.

The following is an analysis by T. Price of a very pure limestone occurring on Little Sulphur Creek, 4 miles east of Geyserville, Sonoma County:

Analysis of limestone from Sonoma County, Cal.[b]

Silica (SiO_2)	1.27
Alumina (Al_2O_3) Iron oxide (Fe_2O_3)	.43
Lime carbonate ($CaCO_3$)	95.20
Magnesia (MgO)	1.32
Water	1.60

REDDING DISTRICT.

The limestones occurring in the Redding district are described as follows by Mr. J. S. Diller in Bulletin 213, United States Geological Survey, page 365:

More limestone occurs in the copper region of Shasta County, Cal., than in an equal area of any other part of the State. A thick limestone of Triassic age occurs along the stage road east of Furnaceville, and subordinate masses crop out around the upper slope of Bear Mountain, a few miles northwest of Sherman, but the principal mass of this belt forms Brock Mountain, on Squaw Creek, and may be traced for many miles to the north. This limestone is full of fossils and is especially noted for the large lizard-like animals it contains. It is generally pure and at Brock Mountain is used for flux in the Bully Hill smelter.

A belt of more prominent limestone ridges and peaks extends from near Lilienthals north by Gray Rock, the Fishery, and Hirz Mountain, along the McCloud for many miles. The limestone where best developed is over 1,000 feet thick, and until recently has been used for flux at Bully Hill. It is cut by numerous irregular dikes

[a] Eighth Ann. Rept. California State Mineralogist, p. 882.
[b] Eighth Ann. Rept. California State Mineralogist, p. 633.

of igneous rock, which locally interfere with quarrying. If the projected branch railroad up Pit River is ever built, it would pass near this great limestone.

A third belt of limestone occurs near Kennett, within a few miles of the railroad, and furnishes not only flux for the Mountain Copper Company at the Keswick smelter, but also lime, which is burned at Kennett and shipped to many points on the Southern Pacific Railroad. This limestone is of Devonian age and consequently much older than the others. Although the limestone is not nearly as large as the others and isolated on ridge crests by igneous rocks, it is more valuable because more accessible. Smaller masses occur near Horsetown and at several points on the plain northeast of Buckeye, where lime has been burned, but since the Kennett locality has been opened they are of little importance.

Below are given partial analyses of three of the limestones above described by Mr. Diller:

Analysis of limestone from Redding district, California.

	1	2	3
Silica (SiO_2)	2.0	4.0	4.4
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	1.5	1.5	n. d.
Lime (CaO)	52.5	51.0	53.3
Magnesia (MgO)	n. d.	n. d.	.5

1. Near U. S. Fishery at Baird. Bull. U. S. Geol. Survey No. 225, p. 176.
2. Brocks Mountain, 6 miles northeast Delamar. Ibid.
3. Kennett. Eighth Ann. Rept. California State Mineralogist, p. 572.

PORTLAND-CEMENT INDUSTRY IN CALIFORNIA.

Until within the past two years only one Portland-cement plant had succeeded in establishing itself in California. This was the California Portland Cement Company, with works located at Colton, in southern California. During 1903, however, two additional plants went into operation, both located near San Francisco. In consequence of the slight development of a local industry, California has been supplied largely with foreign Portlands, always high-priced and frequently of poor quality.

The plant of the Pacific Portland Cement Company is located about 6 miles east of Suisun, Solano County. The materials used are travertine—a very pure lime carbonate deposited from waters carrying it in solution—and clay. Eight rotary kilns are in operation, Bakersfield oil being used for fuel. The electric power necessary for running the plant is derived from Marysville. Analyses of the raw materials and of the finished cement, which is marketed as "Golden Gate" brand, follow:

Analyses of travertine, clay, and cement.

	Travertine.	Clay.	Cement.
Silica (SiO_2)	1.21	58.25	22.25
Alumina (Al_2O_3)	.70	18.56	7.65
Iron oxide (Fe_2O_3)	.50	7.35	3.35
Lime (CaO)	53.62	3.10	62.85
Magnesia (MgO)	.44	1.28	.78
Alkalies (K_2O, Na_2O)	....	2.35	.69
Sulphur trioxide (SO_3)	.11	.45	1.34
Carbon dioxide (CO_2) / Water	42.98	8.55	1.00

The Standard Portland Cement Company plant is located at Napa Junction. Two grades of limestone are used as raw materials, one a very clayey limestone, averaging about 60 per cent lime carbonate; the other a purer rock, carrying 85 per cent or more of lime carbonate. In this respect the materials are closely similar to those used in the Lehigh district of Pennsylvania-New Jersey; but the California limestones are much softer than those of the Lehigh region. Ten rotary kilns are in use, with Bakersfield oil for fuel. Analyses of the raw materials follow:

Analyses of raw materials of cement made at Napa Junction, Cal.

	High-lime rock.	Low-lime rock.
Silica (SiO_2)	7.12	20.87
Alumina (Al_2O_3)	2.36	10.50
Iron oxide (Fe_2O_3)	1.16	3.50
Lime carbonate ($CaCO_3$)	87.70	62.76
Magnesium carbonate ($MgCO_3$)	.84	1.48

The plant of the California Portland Cement Company is located at Colton. The raw materials used are a pure, very highly crystalline limestone (marble), obtained near the plant, and clay shipped in from Perris, 25 miles away. The limestone will range from 90 to 99 per cent lime carbonate; the clay is relatively low in silica and high in alumina and iron oxide. Three rotary kilns are in operation, using Los Angeles and Bakersfield oil for fuel.

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PORTLAND CEMENT RESOURCES OF COLORADO.

PORTLAND CEMENT MATERIALS.

DISTRIBUTION AND COMPOSITION.

For the purposes of the present bulletin the limestones of Colorado may be divided, on a geographical basis, into two groups, those lying west of the Front Range, and those lying east of that range in the plains.

LIMESTONES WEST OF THE FRONT RANGE.

Of the limestones occurring in central and western Colorado, west of the Front Range, those of Mississippian age seem to be of most promise as Portland-cement materials, though limestones occurring in other divisions of the Carboniferous, as well as later and earlier rocks, are occasionally of value for this purpose. Analyses of a number of nonmagnesian limestones are given in the following table:

Analyses of limestones from Colorado west of the Front Range.

No.	Silica (SiO_2).	Alumina (Al_2O_3), iron oxide (Fe_2O_3).	Lime (CaO).	Magnesia (MgO).	Carbon dioxide (CO_2).
1	21.45	1.20	40.64	0.73	32.73
2	6.47	.77	46.65	2.64	39.55
3	3.71	.55	47.40	4.49	42.15
4	2.27	.14	53.79	.46	42.76
5	.22	Trace.	55.17	.21	43.58
6	.23	.09	55.49	.24	43.87
7	.06	....	55.81	....	43.85
8	.22	.20	55.45	.24	43.84
9	.11	.10	55.68	Trace.	43.75
10	6.54	.92	50.58	.36	40.18
11	1.44	.13	54.98	Trace.	n. d.
12	5.32	.91	48.73	2.95	41.71
13	.51	.10	55.50	.17	43.82
14	2.37	.19	53.64	.73	42.93

Analyses of limestones from Colorado west of the Front Range—Continued.

No.	Silica (SiO_2).	Alumina (Al_2O_3), iron oxide (Fe_2O_3).	Lime (CaO).	Magnesia (MgO).	Carbon dioxide (CO_2).
15	.33	Trace.	55.81	.16	44.03
16	4.13		53.00	.59	42.28
17	.75	1.00	53.40	.45	42.46
18	n. d.	n. d.	53.20	n. d.	n. d.
19	31.12	.55	37.28	.54	29.88
20	2.04	.15	54.62	.25	43.28
21	.82	.07	55.47	.22	43.86
22	.36	.17	55.58	.37	44.17
23	4.42	.10	52.97	.40	42.12
24	.62	.25	55.24	.24	43.81
25	7.91	.32	50.83	.70	40.90
26	1.75	.32	53.60	1.23	43.65
27	2.69	.21	54.23	.21	42.97

1-9. Glenwood Springs, Garfield County. George Steiger, analyst. Bull. U. S. Geol. Survey No. 168, p. 273.
10. North Park, Grand County. B. E. Brewster, analyst. Fortieth Par. Survey, vol. 2, p. 115.
11. Gunnison County. Ann. Rept. Colorado School Mines for 1887, p. 21.
12. Morrison, Jefferson County. L. G. Eakins, analyst. Bull. U. S. Geol. Survey No. 168, p. 270.
13. Mount Silverheels, Park County. W. F. Hillebrand, analyst. Ibid., p. 272.
14. Fairplay, Park County. W. F. Hillebrand, analyst. Ibid.
15. Aspen, Pitkin County. L. G. Eakins, analyst. Ibid., p. 273.
16. Aspen Mount, Pitkin County. Reese & Richards, analysts. Rept. Colorado School Mines, 1886, p. 67.
17. Aspen Mount, Pitkin County. F. Bardwell, analyst. Ibid.
18. Aspen Mount, Pitkin County. F. Buckley, analyst. Ibid., p. 68.
19. Aspen district, Pitkin County. George Steiger, analyst. Bull. U. S. Geol. Survey No. 168, p. 272
20. Jacque Mount, Tenmile district, Summit County. W. F. Hillebrand, analyst. Bull. U. S. Geol. Survey No. 168, p. 274.
21. Near Sabbath Rest tunnel, Tenmile district, Summit County. W. F. Hillebrand, analyst. Ibid.
22. Searls Gulch, Tenmile district, Summit County. W. F. Hillebrand, analyst. Ibid.
23. North of Sugarloaf, Tenmile district, Summit County. W. F. Hillebrand, analyst. Ibid.
24, 25. Pittston tunnel, Tenmile district, Summit County. W. F. Hillebrand, analyst. Ibid.
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LIMESTONES EAST OF THE FRONT RANGE

In the eastern portion of Colorado the surface rocks are of Cretaceous or later age. While mostly made up of clays and sands, these rocks contain one limestone formation of great importance as a possible source of Portland-cement material. This is the Niobrara limestone of the Cretaceous.

The areas in which the Niobrara limestone outcrops in eastern Colorado, as shown on the Hayden map, may be described as follows:

One belt of Niobrara limestone enters Colorado from Nebraska, following the South Platte and ending between Fort Morgan and Greeley. Another belt enters the State from Wyoming, at a point just west of the Colorado and Southern Railroad, and runs about due south, as a band from 1 to 6 miles in width, the towns of Laporte, Namaqua, and

Boulder being near its western edge, while Fort Collins, Big Thompson, Berthoud, Valmont, and Marshall lie on or near its eastern border. This belt thins out southward near Golden, turns slightly east of south at a point just east of Morrison, and disappears west of Larkspur.

Another belt commences about 10 miles north of Colorado Springs, and covers a wide area east and west of the Denver and Rio Grande Railway. The towns of Colorado Springs, El Paso, Fountain, Pueblo, and St. Charles are located on this limestone belt, while Sunview and Turkey Creek lie on its west border. Arms of this belt are extended up Arkansas River as far as Canyon, and up Huerfano River to Huerfano Park, reaching almost to Dixon. The stations of Granero, Huerfano, Cucharas, Santa Clara, Placito, Walsenburg, Apishapa, and Trinidad are located on the southern portion of this belt.

PORTLAND-CEMENT INDUSTRY IN COLORADO.

Only one Portland-cement plant is at present in operation in Colorado, but several attempts have been made to manufacture cement in the State. The materials used at the present plant, as well as at all the previous plants, are limestones of various grades of purity, from the Niobrara formation.

The plant of the Portland Cement Company of Colorado is located about 8 miles east of Florence, Fremont County, south of Arkansas River. The materials used are an argillaceous limestone averaging about 71 per cent of lime carbonate, and a purer limestone carrying about 88 per cent of lime carbonate. The former occurs in several beds, aggregating about 60 feet in thickness; the purer limestone is taken from a 40-foot bed lying about 50 feet below the other. Six rotary kilns are in place, using oil from the Florence field as fuel.

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PORTLAND-CEMENT RESOURCES OF CONNECTICUT.

While many outcrops of limestone occur within the limits of the State of Connecticut, few of them, unfortunately, are large enough to justify the erection of a cement plant. In addition to this disadvantage, most Connecticut limestones carry entirely too high a percentage of magnesium carbonate to be considered available as

Portland-cement materials. This last statement is particularly true of the thick and extensive limestone beds of western Connecticut, which are so extensively quarried and utilized for lime burning in the vicinity of Danbury, Canaan, etc. Numerous analyses of these limestones show that they rarely carry less than 20 per cent of magnesium carbonate, while they often run as high as 40 per cent of that constituent. The nonmagnesian limestones, on the other hand, which occur chiefly in central and eastern Connecticut, are rarely over a few feet in thickness, or else have a very limited area of outcrop.

Of the analyses given below Nos. 2 and 3 are fairly typical of most of the limestones of western Connecticut. They are in general quite pure, carrying usually very low percentages of silica, alumina, iron oxide, etc., but they are at the same time almost invariably high in magnesia, often approaching dolomite in composition. Occasionally beds are found which show very low magnesia percentages. An example of this is afforded by analysis No. 1. Such limestones would of course be serviceable as Portland-cement materials, but the trouble is that these low-magnesia beds are not extensive, nor can they be told, at sight, from high-magnesia rocks occurring in the same quarry. It would therefore be impracticable to separate the two kinds of rock during quarrying, and for this reason the writer believes that such occasional occurrences of low-magnesia rocks give no promise of a future Portland-cement industry in Connecticut.

Analyses of limestones from Connecticut.

	1	2	3
Silica (SiO_2)	5.83	0.08	0.48
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	3.90	.25	.20
Lime (CaO)	50.40	30.46	31.31
Magnesia (MgO)	.10	21.48	21.03
Carbon dioxide (CO_2)	39.72	47.58	46.98

1. Quarry of Danbury Lime Company, Danbury, Fairfield County. Mineral Resources U. S. for 1889–1890, p. 386.
2. Quarry of Canaan Lime Company, Canaan, Litchfield County. Twentieth Ann. Rept. U. S. Geol. Survey, pt. 6, p. 370.
3. Quarry of Canfield Bros., East Canaan, Litchfield County. Ibid.

PORTLAND-CEMENT RESOURCES OF DELAWARE.

No limestones occur within the limits of Delaware, with the exception of small isolated outcrops in the crystalline rocks of the extreme northern portion of the State. Though some of these furnish rock low in magnesia, the outcrops are entirely too small to be worth considering.

PORTLAND-CEMENT RESOURCES OF FLORIDA.

Though Florida is largely underlain by beds of limestone of Tertiary and recent age, these are covered, over great areas, by later deposits of sand and gravels. Owing partly to this, and more largely to the lack of local fuel deposits and cement markets, no attempt has ever been made to manufacture Portland cement in the State. Should commercial conditions ever change so as to render a local cement industry possible there will probably be little difficulty in locating deposits of limestone suitable for use as Portland-cement material, for the St. Stephens limestone, which is so promising a source of cement material in Alabama (see pp. 77–81), covers a large area in northern Florida, while other limestones of equal value as cement materials outcrop elsewhere in the State.

The analyses in the following table give some idea of the composition of various Florida limestones.

Analyses of limestones from Florida.

	1	2	3	4	5	6	7	8	9
Silica (SiO_2)	39.01	12.31	0.17	0.25	0.12	0.19	0.07	2.94	8.50
Alumina (Al_2O_3)	1.20	12.19	.20	.17	} .08	.16	.16	.23	.73
Iron oxide (Fe_2O_3)	.53	.66	.07	.07					
Lime (CaO)	30.99	26.28	54.03	54.01	54.38	55.12	54.02	51.51	47.29
Magnesia (MgO)	.42	16.72	.29	.77	.86	.30	1.06	.71	1.51
Alkalies (Na_2O, K_2O)	.71	.50	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.
Sulphur trioxide (SO_3)	.33	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.
Carbon dioxide (CO_2)	24.25	38.12	42.52	42.84	43.36	43.28	43.20	41.59	39.00
Water	3.07	2.99	n. d.	n. d.	n. d.	n. d.	n. d.	2.64	3.37

1. St. Stephens limestone, Wakulla County. Vol. 6, Tenth Census Reports, p. 193.
2. River Junction, Escambia County. George Steiger, analyst. Bull. U. S. Geol. Survey No. 168, p. 257.
3. Artesian well, Key West, 25 feet down. George Steiger, analyst. Ibid.
4. Artesian well, Key West, 100 feet down. George Steiger, analyst. Ibid.
5. Artesian well, Key West, 150 feet down. George Steiger, analyst. Ibid.
6. Artesian well, Key West, 1,400 feet down. George Steiger, analyst. Ibid.
7. Artesian well, Key West, 2,000 feet down. George Steiger, analyst. Ibid.
8. Shell rock, near Fort Worth. F. W. Clarke, analyst. Ibid.
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PORTLAND-CEMENT RESOURCES OF GEORGIA.

PORTLAND-CEMENT MATERIALS.

One Portland-cement plant is already in operation in Georgia, and the prospects for some extension of the industry seem good, though the local market, unless it improves materially, will not justify any great expansion.

Four series of limestones occurring in Georgia are worth consideration here. Beginning with the oldest formation, these four are:

1. Metamorphic limestones (marbles) of uncertain age.
2. Chickamauga limestone of Ordovician (Lower Silurian) age.
3. Bangor limestone of Mississippian (Lower Carboniferous) age.
4. Cretaceous and Tertiary limestones (so-called "marls").

The distribution of these limestones in the western portion of the State is shown on the geologic map, Pl. II.

METAMORPHIC LIMESTONES OR MARBLES.[a]

DISTRIBUTION.

Highly crystalline limestones, suitable for use as marble, occur in parts of northern Georgia, notably in the counties of Fannin, Gilmer, Pickens, and Cherokee. The principal outcrops in this district occur in a belt closely parallel to the line of the Murphy and North Georgia Railroad, extending from near Canton northward to the Georgia-North Carolina line. Throughout the entire extent of this belt the marble has been quarried more or less extensively.

COMPOSITION.

As shown by the analyses quoted by S. W. McCallie, two quite distinct types of marble occur, so far as chemical composition is concerned. One of these types rarely carries over 1 per cent of magnesia, and is therefore available as a Portland-cement material. The analyses given in the following table are fairly representative of this type. The other type of marble carries 15 to 22 per cent of magnesia, and is therefore not worth considering in the present connection:

Analyses of metamorphic limestones from Georgia.[b]

	1	2	3	4	5
Silica (SiO_2)	0.35	1.62	2.12	1.43	0.76
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	.15	.32	.10	3.28	.42
Lime (CaO)	55.00	54.41	54.06	52.77	54.67
Magnesia (MgO)	1.12	.75	.90	.82	1.01
Carbon dioxide (CO_2)	44.16	43.13	42.86	41.85	43.49

1. "Creole" marble, Georgia Marble Company's quarry, near Tate, Pickens County.
2. "Etowah" marble, Georgia Marble Company's quarry, near Tate, Pickens County.
3. Coarse white marble, Georgia Marble Company's quarry, near Tate, Pickens County.
4. Haskins property, 1 mile southeast Red Clay, Whitfield County.
5. Ellinger property, 1 mile east Varnells station, Whitfield County.

[a] The composition, character, and distribution of these valuable building stones are described in Bulletin No. 1, of the Georgia Geological Survey, by S. W. McCallie, entitled "Preliminary Report on the Marbles of Georgia." To this bulletin reference should be made for details concerning the crystalline limestones of Georgia.

[b] Analyses 1 to 5 of the table are from the report by Prof. S. W. McCallie on the "Marbles of Georgia," issued as Bulletin No. 1 of the Georgia Geological Survey. All these analyses were made by Prof. W. H. Emerson.

CHICKAMAUGA LIMESTONE.

DISTRIBUTION.

The Chickamauga limestone occurs only in northwest Georgia, appearing as a series of long, narrow bands, which usually trend N. 30° E. The distribution of this limestone is shown on Pl. II. page 62. A few of the more prominent areas will be briefly described, beginning in the extreme northeastern portion of the State, particular attention being paid to outcrops located on or near railroads.

A belt of Chickamauga limestone enters Georgia a few miles southwest of Chattanooga, the Alabama Great Southern Railroad running on this limestone belt from near Chattanooga to a few miles below Trenton; another belt is crossed by the same railroad about 3 miles south of Rising Fawn; a third belt is followed closely by the Southern Railroad from Rossville to Cedar Grove, and another belt is followed by the same road from Bronco to Menlo. The line from Chattanooga to Summerville runs, for 5 miles east of Chickamauga, across one of these limestone belts. An extensive belt of the limestone borders the western faces of Taylors Ridge and White Oak Mountains, but is crossed by railroads only at two points, near Ringgold and Lavender, respectively. Other belts are crossed at Dalton and between Dalton and Tunnelhill.

The Chickamauga limestone is very extensively exposed in the northern half of Polk County, being crossed by railroads at or near the stations of Esomhill, Cedartown, Fish Creek, Rockmart, Davittes, and Taylorsville. As later noted, one Portland-cement plant is already in operation at Rockmart utilizing this limestone.

COMPOSITION.

Throughout its range in Georgia the Chickamauga limestone is commonly a rather pure rock, carrying 90 to 95 per cent of lime carbonate with less than 2 per cent of magnesium carbonate. Analyses 1, 2, and 4 of the following table are fairly representative of the usual composition of the Trenton limestone. Analysis 3, on the other hand, represents a highly magnesian type of rock that is fortunately uncommon in this series.

Analyses of Chickamauga limestones from Georgia. [a]

	1	2	3	4
Silica (SiO_2)	2.82	....	8.16	2.30
Alumina (Al_2O_3) Iron oxide (Fe_2O_3)	1.80	2.23	9.50	.40
Lime carbonate ($CaCO_3$)	91.40	94.37	55.47	95.20
Magnesium carbonate ($MgCO_3$)	3.75	2.10	25.33	2.17

1. South of Trenton, Polk County. J. M. McCandless, analyst.
2. Cedartown, Polk County. W. J. Land, analyst.
3. Near Trenton, in valley of Lookout Creek. J. M. McCandless, analyst.
4. Devitte lime quarry, 5 miles northeast of Rockmart, Polk County. Chemist, Cherokee Iron Company, analyst.

BANGOR LIMESTONE.

DISTRIBUTION.

The Bangor limestone in Georgia occurs only in Dade, Walker, and the northwestern portion of Chattooga counties. In this area it appears as a series of belts from one-half to almost 2 miles in width, following closely the trend of Sand, Lookout, and Pigeon mountains, and usually running up high on the flanks of these mountains, as well as occupying parts of the valleys at their feet.

COMPOSITION.

The Bangor limestone in its Georgia areas varies between 700 and 900 feet in thickness. The greater part of this is a rather heavy-bedded blue limestone, commonly quite pure and low in magnesia. Toward the top of the formation the limestone becomes more clayey, and interbedded shales become more and more frequent.

Analyses of Bangor limestone from Georgia.

	1	2
Silica (SiO_2)	0.95	12.70
Alumina (Al_2O_3) Iron oxide (Fe_2O_3)	1.00	3.20
Lime carbonate ($CaCO_3$)	96.13	80.60
Magnesium carbonate ($MgCO_3$)	2.05	2.45

1. Rising Fawn, Dade County, J. M. McCandless, analyst. "Paleozoic Group of Georgia," p. 271.
2. Side of Sand Mountain, Polk County, J. M. McCandless, analyst. Ibid., p. 271.

[a] Taken from a report by Prof. J. W. Spencer on the "Paleozoic Group of Georgia," issued by the Georgia Geological Survey. The composition of No. 3 is very different from that of normal Chickamauga limestones, and its reference may therefore be erroneous.

CRETACEOUS AND TERTIARY LIMESTONES.

DISTRIBUTION.

The portion of Georgia lying south and southeast of a line drawn through Knoxville to Columbus is occupied by clays, gravels, and soft limestones of Tertiary and Cretaceous age. The limits of these formations have never been accurately mapped, so that the distribution of the soft limestone beds can be stated only in a general way. Several areas of the soft limestones (commonly called "marls" in geological and agricultural reports) are known to occur. One of these areas is the continuation of that described as the St. Stephens limestone of Alabama. A detailed description of the character of this limestone, with numerous analyses from Alabama localities, will be found on pages 77–83 of this bulletin. In Georgia this limestone occupies most of the counties of Decatur, Miller, Baker, Mitchell, Dougherty, and Lee. The only analysis of it from a Georgia locality is given as No. 6 of the table below. Other limestone beds occur in the Creta ceous and Tertiary region, but little is known concerning their distribution.

COMPOSITION.

Such analyses as are available are presented in the following table. They all show the presence of considerable percentages of silica, alumina, and iron oxide, but are at the same time remarkably low in magnesia.

Analyses of Cretaceous and Tertiary limestones from Georgia.

	1	2	3	4	5	6
Silica (SiO_2)	8.90	6.30	9.63	13.86	13.86	14.44
Alumina (Al_2O_3)	.55	.41	.62	1.11	1.76	1.33
Iron oxide (Fe_2O_3)	3.22	1.65	4.31	2.08	3.02	2.65
Lime (CaO)	50.14	49.87	46.76	45.65	43.67	42.88
Magnesia (MgO)	.05	.12	.05	.08	.04	.15
Carbon dioxide (CO_2)	37.05	39.21	36.52	34.87	34.12	31.96
Water	1.23	1.63	1.31	1.19	1.45	1.63

1. Reddick's quarry, Screven County. Reports Tenth Census, vol. 6, p. 312.
2. Washington County. Ibid.
3. Shell Bluff, Burke County. Ibid.
4. Houston County. Ibid.
5. Near Montezuma, Macon County. Ibid.
6. Near Albany, Dougherty County. Ibid.

PORTLAND-CEMENT INDUSTRY IN GEORGIA.

Only one Portland-cement plant is at present operating in Georgia, and this plant is of very recent construction. It is owned by the Southern States Portland Cement Company, and is located about half

a mile east of the village of Rockmart, Polk County, Ga. The Portland cement manufactured here is made from a mixture of pure limestone and slate, both of which materials occur in the immediate vicinity of the plant.

Hard blue slates, which have been extensively quarried for structural purposes, outcrop on the hills south of Rockmart. These slates are of Ordovician age and have been described as the "Rockmart slates" by Doctor Hayes. East of the town the surface rock is the "Chickamauga limestone," which here contains beds of pure nonmagnesian limestone which have been quarried at several points in the vicinity and burned into lime.

The cement company purchased the property of the old Georgia Slate Company, about one-half mile southwest of Rockmart, and carried on extensive operations with the diamond drill. The intention was to quarry the slate, sell as slate the portions best suited for that use, and utilize the scrap and waste in the manufacture of cement. The quarries from which the limestone is obtained are located one-half mile east of town, near the mill. The president of the cement company is Mr. W. F. Cowhan, who is also connected with the Peninsular Portland Cement Company, of Jackson, Mich., and the National Portland Cement Company, of Durham, Ontario.

Analyses of slate and limestone from the particular quarries which it is intended to work could not be obtained. Dr. J. W. Spencer, however, quotes analyses of similar material from the vicinity, and these will serve to indicate the character of the material which will be used:

Analyses of slate and limestone from Rockmart, Georgia.

	Slate.	Limestone.	
		1	2
Silica (SiO_2)	61.66	....	0.40
Alumina (Al_2O_3)	19.64	2.23	
Iron oxide (Fe_2O_3)	7.54	....	....
Lime carbonate ($CaCO_3$)	....	94.37	95.20
Magnesium carbonate ($MgCO_3$)	....	2.10	2.17
Soda (Na_2O)	1.05	....	....
Potash (K_2O)	1.27	....	....

IDAHO.

Small isolated areas of crystalline limestone (marble) occur in the western portion of the State, but no extensive areas of limestone are known to occur.

PORTLAND-CEMENT RESOURCES OF ILLINOIS.

PORTLAND-CEMENT MATERIALS.

Low magnesia limestones, suitable for use in Portland-cement manufacture, occur in Illinois in three different geologic groups. The limestones of these groups will be discussed in the following order: (1) Trenton limestones, (2) Mississippian limestones, (3) Coal Measures limestones.

Of the three groups named above only one, the Coal Measures, has yet been utilized in Illinois as a source of Portland-cement material, though the Mississippian limestones, when their location, thickness, and composition are considered, would seem to be the most promising group of the three. The Trenton group occurs in large areas, but only a small part of the limestones usually included in it are sufficiently low in magnesia to be worth considering.

TRENTON LIMESTONE.

DISTRIBUTION.

Though the so-called Trenton limestone covers a very large part of northern Illinois, it seems, in this part of the State, to be almost entirely a high-magnesia rock, and therefore unavailable as a source of Portland-cement material. In western and southwestern Illinois, however, along the bank of Mississippi River, a number of isolated areas of Trenton limestone occur, and the rock from these localities, to judge from the analyses available, is sufficiently low in magnesia to be used in Portland-cement manufacture.

The geologic map (Pl. IX, p. 220) shows the location of four separate areas of Trenton limestone in the district considered The first of these areas occurs on the east bank of Mississippi River at and below Thebes for a mile or two. The second area, larger than this, extends along the east bank of Mississippi River from Harrisonville to Smiths Landing, in the northern part of Monroe County. A third area is exposed along both banks of Illinois River, near Hartford, in Jersey County. The fourth area shown on the map occurs along the east bank of Mississippi River, south of Harding, in Calhoun County.

COMPOSITION.

The only available analysis of Trenton limestone from any of these areas in southwestern Illinois is that given below. It shows a very pure nonmagnesian limestone. Similar occurrences of nonmagnesian limestones in the Trenton series across the river in Missouri will be found discussed on page 221, where further analyses are given.

Analyses of Trenton limestone from Thebes, Alexander County, Ill.[a]

[H. Pratten, analyst.]

Silica (SiO_2)	0.06
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	.20
Lime carbonate ($CaCO_3$)	98.01
Magnesium carbonate ($MgCO_3$)	1.59
Water	1.07

MISSISSIPPIAN LIMESTONES.

DISTRIBUTION.

The Mississippian limestones occur only in one belt, which extends through western and southern Illinois. The northern end of this belt is near New Boston, in Mercer County. From this point the limestones extend southward along Mississippi River, in a belt averaging, perhaps, 20 miles in width, through Henderson, Hancock, Adams, and Pike counties. A narrow branch of this belt extends up Illinois River as far as Beardstown, and narrower bands border several of the larger tributaries of the Illinois. The main belt continues southward, parallel to and usually bordering Mississippi River, and covers the greater part of Scott, Greene, and Jersey counties. Near Alton the limestone belt contracts until it is only a few miles in width, but widens out again a few miles south of Alton, and covers extensive areas in Madison, St. Clair, Monroe, Randolph, and Jackson counties. Near the southern boundary of Jackson County the belt leaves the Mississippi and turns eastward through Union, Johnson, Pope, and Hardin counties.

COMPOSITION.

As in other States, the Mississippian limestones of Illinois are in general rather well adapted for use as Portland-cement materials. Occasionally they contain beds carrying too much magnesium carbonate for this use, but the commonest type is a limestone containing say 90 to 95 per cent of lime carbonate, 1 to 4 per cent magnesium carbonate, and 1 to 6 per cent of silica, alumina, and iron oxide. The analyses given below are therefore fairly representative of the Mississippian limestones of Illinois.

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[a] Geology of Illinois, vol. 1, p. 148.

Analyses of Mississippian limestones from Illinois.

	1	2	3	4	5
Silica (SiO_2)	0.05	0.37	2.72	12.50	0.47
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	.20	.27	1.06	2.10	2.18
Lime carbonate ($CaCO_3$)	94.68	92.77	90.86	82.48	95.62
Magnesium carbonate ($MgCO_3$)	4.31	6.75	3.18	....	.82

1. Quincy, Adams County. H. Pratten, analyst. Geology of Illinois, vol. 1, p. 108.
2. Quincy, Adams County. C. G. Hopkins, analyst. Twentieth Ann. Rept. U. S. Geol. Survey, pt. 6, p. 377.
3. Rosiclare, Hardin County. H. Pratten, analyst. Geology of Illinois, vol. 1, p. 374.
4. Nauvoo, Hancock County. H. Pratten, analyst. Ibid., p. 99.
5. Marblehead, Adams County. N. G. Bartlett, analyst. Twentieth Ann. Rept. U. S. Geol. Survey, pt. 6, p. 377.

PENNSYLVANIA ("COAL MEASURES") LIMESTONES.

DISTRIBUTION.

The Pennsylvania ("Coal Measures,") rocks of Illinois cover most of the State south of a line drawn through Paxton, Wilmington, Lasalle, Princeton, and Rock Island. The greater part of this thick series of Coal Measure rocks consists of shales and sandstones, but the presence of occasional relatively thin beds of limestone is of interest, for it is from these limestone beds of the Coal Measures that three of the four[a] Portland-cement plants now operating in Illinois draw their supply of raw material.

The limestones occurring in the Coal Measures of Illinois are usually thin, but fairly persistent. One thick bed, or series of beds, is well exposed near Lasalle and Oglesby, showing a total thickness of 20 to 25 feet of limestone.

The following geologic section at Lasalle, Lasalle County, will serve to indicate the position of one of the principal beds of Coal Measure limestone. The beds are given in descending order, and bed No. 5 is the limestone used by the three Portland-cement plants located at and near Lasalle.

Section at Lasalle, Ill.[b]

		Feet.
(1)	Shales	37
(2)	Blue limestone	1
(3)	Bituminous shale and coal	2
(4)	Shales	32
(5)	Limestone	20
(6)	Bituminous shale and coal	36
(7)	Fire clay (sometimes absent).	
(8)	Shale	17
(9)	Limestone	2
(10)	Shale.	

[a] The fourth plant uses slag.

[b] Report Illinois Board World's Fair Commissioners, 1893, p. 129.

In the cut on the Illinois Central Railroad north of the zinc-smelting works at Lasalle the following section is shown:

Section near Lasalle, Ill.[a]

		Feet.
(1)	Green and ash-gray shales	4
(2)	Nodular calcareous shale	3
(3)	Greenish shale	12
(4)	Impure chocolate-colored limestone	2
(5)	Red and green shales	10
(6)	Green shaly clay	8
(7)	Shaly limestone	6
(8)	Upper main limestone	12
(9)	Green shale	2
(10)	Lower limestone	12

Beds 8, 9, and 10 of this section, taken together, represent bed No. 5 of the preceding section. The shale parting which here separates the two limestone beds increases in thickness farther south, until at Peru 6 or 8 feet of shale intervene between the two beds of limestone. This limestone series occurs at about the horizon of coal bed No. 9 of the Illinois reports, and is probably the same as the limestones exposed near Carlinville.

COMPOSITION.

The Coal Measures limestones, though usually high in clayey impurities, are commonly low in magnesium carbonate. The analyses given in the following table are of the more argillaceous limestones. Analyses of purer rocks, used at three Portland-cement plants in the State, will be found on pages 136 and 137.

Analyses of Coal Measure limestones from Illinois.

	1	2	3	4	5	6
Silica (SiO_2)	7.54	17.11	18.54	13.89	19.49	10.27
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	3.43	1.97	3.91	2.61	3.71	15.32
Lime (CaO)	45.57	44.44	42.03	45.91	41.75	38.49
Magnesia (MgO)	4.36	1.12	1.54	1.00	1.21	2.41

1-5. Lasalle County.
6. Sugar Creek, Sangamon County, H. Pratten, analyst. Geology of Illinois, vol. 1, p. 60.

PORTLAND-CEMENT INDUSTRY IN ILLINOIS.

Four Portland-cement plants are at present in operation in Illinois. Three of these plants use limestones and shales from the Coal Measures; the fourth utilizes a mixture of blast-furnace slag and limestone.

[a] Rept. Geol. Survey Illinois, vol. 7, p. 46-47.

The Chicago Portland Cement Company plant is located at Oglesby, Lasalle County. The following section is exposed in their quarry, from above downward:

Section at quarry of Chicago Portland Cement Co., Oglesby, Ill.

Limestones	feet..	28
Black slaty shale	do...	6
Coal	inches..	3
Harder gray shale	feet..	9

The raw materials used at the plant are limestone from this quarry and shale from both of the beds noted. Analyses of the raw materials are given in the following table, that of the shale being from the 6-foot bed of black shale:

Analyses at cement materials from Oglesby, Ill.

	Limestone.	Shale.
Silica (SiO_2)	6.06	53.12
Alumina (Al_2O_3)	3.92	20.60
Iron oxide (Fe_2O_3)		4.09
Lime (CaO)	49.46	4.02
Magnesia (MgO)	.91	2.24
Sulphur trioxide (SO_3)	.10	n. d.
Carbon dioxide (CO_2)	39.06	13.70
Water		

The plant of the German-American Portland Cement Company is located just east of Lasalle. The quarry shows 8 to 10 feet of limestone, underlain by 3 to 3½ feet of blue shale, and this in turn is underlain by 11 to 12 feet of limestone. Other shales outcrop beneath the lower limestone, but are not at present used in the cement plant. Analyses of the raw materials, made by Mr. W. E. Prüssing, follow.

Analyses of cement materials from Lasalle, Ill.

	Limestone.		Shale.
Silica (SiO_2)	5.43	5.06	52.74
Alumina (Al_2O_3)	1.43	2.32	21.73
Iron oxide (Fe_2O_3)			
Lime (CaO)	52.02	48.29	12.37
Magnesia (MgO)	1.11	3.66	2.01
Carbon dioxide (CO_2)	40.24	41.05	11.27
Water			

The plant of the Marquette Cement Company is located at Dickinson, about 5 miles south of Lasalle. The limestone used is derived from the two heavy beds included in the Coal Measures of this district

and noted in the sections given on pages 134 and 135. Shales occurring below the limestone are mined to complete the mixture. Analyses of the raw materials used are as follows:

Analyses of cement materials from Dickinson, Ill.[a]

	Limestone.	Shale.
Silica (SiO_2)	8.20	54.30
Alumina (Al_2O_3)	1.30	19.33
Iron oxide (Fe_2O_3)		5.57
Lime (CaO)	49.37	3.29
Magnesia (MgO)	.85	2.57
Sulphur (S)	n. d.	2.36
Carbon dioxide (CO_2)	39.72	n. d.

The fourth Portland cement plant in the State is that of the Illinois Steel Company. This is located at Chicago, and uses a mixture of blast-furnace slag and crushed limestone.

BIBLIOGRAPHY OF CEMENT RESOURCES OF ILLINOIS.

In addition to the few papers listed below data on limestones and clays are scattered through the various volumes of reports issued by the Illinois geological survey.

Conover, A. D. [Limestones and sandstones of Illinois.] Reports Tenth Census, vol. 10, pp. 219–226. 1884.

Ries, Heinrich. [Clays of Illinois.] Prof. Paper U. S. Geol. Survey No. 11, pp. 94–97. 1903.

PORTLAND-CEMENT RESOURCES OF INDIANA.

PORTLAND-CEMENT MATERIALS.

Three of the geologic groups represented on the map of Indiana (Pl. XII, p. 270) contain limestones which seem worthy of consideration as sources of cement materials. These three groups are: (1) Cincinnati shales and limestones; (2) Mississippi limestones and shales; (3) limestones of the Coal Measures.

In addition to the three formations named, whose areas of outcrop are shown on the map, a fourth source of cement is found in the fresh-water marls of Quaternary age.

ORDOVICIAN SHALES AND LIMESTONES.

CINCINNATI SHALES AND LIMESTONES.

DISTRIBUTION.

The Cincinnati group occurs only in southeastern Indiana, occupying part or all of the counties of Union, Wayne, Fayette, Franklin, Dearborn, Ohio, Switzerland, Ripley, and Jefferson. In this area it is

[a] Twentieth Ann. Rept. U. S. Geol. Survey, pt. 6, p. 544. Analyses furnished by company.

made up of bluish thin-bedded limestones interbedded with soft bluish-green calcareous shales. Toward the top of the series massive sandy limestone beds, brownish in color, occur.[a]

COMPOSITION.

No analyses of the limestones and shales of this series from Indiana localities are available, but on pages 173 and 270 will be found a number of analyses of similar materials from adjoining areas in Ohio and Kentucky.

MISSISSIPPIAN ("LOWER CARBONIFEROUS") LIMESTONES AND SHALES.

As shown on the geologic map, Pl. XII, the Mississippian rocks occur in Indiana in a belt averaging 20 miles or more in width and extending from Ohio River in a general northwesterly direction to the Indiana-Illinois line. Another area underlies Elkhart, Lagrange, and St. Joseph counties, in the extreme northern part of the State.

The Mississippian rocks as thus mapped include several distinct formations. Beginning at the top there are (*a*) Kaskaskia group: sandstones, shales, and limestones; (*b*) Mitchell limestone; (*c*) Bedford oolitic limestone; (*d*) Harrodsburg limestone; (*e*) Knobstone group: shales and shaly sandstones.

KASKASKIA OR HURON GROUP.

These rocks are from 100 to 150 feet thick and are immediately overlain by the heavy Mansfield sandstone of the Coal Measures. The group includes several beds of limestone interbedded with sandstones and shales. In view of the nearness of the thick and valuable Mitchell and Bedford limestones it seems improbable that the limestones of the Kaskaskia group will become of importance as cement materials.

MITCHELL FORMATION.

This formation, lying below the Kaskaskia group and above the Bedford limestone, is a thick series of limestones with occasional thin beds of shale. The series varies in thickness from 150 to 250 feet.

BEDFORD LIMESTONE.

This formation varies in thickness from 30 to 90 feet, or even less, the greater thicknesses being in the area from Bedford to Salem. The Bedford limestone is the well-known oolitic rock—a creamy white limestone, soft when freshly quarried, but hardening rapidly on exposure.

HARRODSBURG LIMESTONE.

Underlying the Bedford limestone is the Harrodsburg limestone, a series ranging from 30 to 100 feet in thickness and made up mostly of limestones, with occasional thin beds of shale.

[a] These occur so seldom (only locally in Clark and Jefferson counties) that the fact is hardly worth mentioning. The lower 200 feet consist almost entirely of shale, and in the next 200 feet the limestones are more abundant than in other parts of the series.

KNOBSTONE GROUP.

The lowest member of the Mississippian is the Knobstone group. This is about 400 feet in thickness, and is made up of shales and shaly sandstones. The Knobstone series is of interest in the present connection because the shale used at one of the Portland-cement plants of the State is derived from it.

COMPOSITION.

The composition of the Mississippian limestones of Indiana is shown by the following analyses:

Analyses of Mississippian limestones from Indiana. [a]

No.	Silica (SiO_2).	Alumina (Al_2O_3), iron oxide (Fe_2O_3).	Lime carbonate ($CaCO_3$).	Magnesium carbonate ($MgCO_3$).
1	0.50	0.98	96.60	0.27
2	.70	.91	96.79	.23
3	1.74	.29	95.62	.89
4	1.60	.18	95.55	.93
5	.65	1.00	95.54	.40
6	.90	3.00	95.00	.22
7	1.13	1.06	96.04	.72
8	.31	.32	98.09	....
9	.48	.15	98.91	.63
10	.84	.13	97.39	.78
11	.86	.16	98.11	.92
12	.64	.15	98.27	.84
13	.76	.15	98.16	.97
14	1.26	.18	97.90	.65
15	1.69	.49	97.26	.77
16	.63	.39	98.20	.81
17	.15	.64	93.80	4.01
18	.50	.71	93.07	4.22

1. Chicago and Bedford Stone Company, Bedford, Lawrence County. Indiana Geol. Surv., 1878, p. 95.
2. Simpson and Archer quarry, near Spencer. Ibid., p. 94.
3, 4, 5. Dunn & Co., Bloomington. Twenty-first Rept. Indiana Dept. Geol., p. 320.
6. Monroe Marble Company, Stinesville. Indiana Geol. Rep., 1862, p. 137.
7. Salem. Idem, 1886, p. 144.
8. Stockslager quarry, Harrison County. Idem, 1878, p. 96.
9. Milltown. W. A. Noyes, analyst. Twenty-seventh Rept. Indiana Dept. Geol., p. 98.
10. Acme Bedford Stone Company, Clear Creek, Monroe County. Twentieth Ann. Rept. U. S. Geol. Survey, pt. 6, p. 381.
11. Hunter Brothers' quarry, Hunter Valley. W. A. Noyes, analyst. Twenty-first Rept. Indiana Dept. Geol., p. 320.
12. Indiana Stone Company, Bedford, Lawrence County. W. A. Noyes, analyst. Ibid.
13. Twin Creek Stone Company, Salem, Washington County. W. A. Noyes, analyst. Ibid.
14. Romona Oolitic Stone Company, Romona, Owen County. W. A. Noyes, analyst. Ibid.
15-16. Hoosier Stone Company, Bedford, Lawrence County. F. W. Clarke, analyst. Bull. U. S. Geol. Survey No. 42, p. 140.
17-18. Indiana Steam Stone Works, Big Creek. L. H. Streaker, analyst. Twenty-first Rept. Indiana Dept. Geol., p. 320.

[a] These analyses are mostly of the Bedford limestone.

LIMESTONES OF THE PENNSYLVANIA SERIES (COAL MEASURES).

Limestone beds occur in the Coal Measures of Indiana, but details regarding their distribution and composition are lacking. On pages 134–135 will be found a discussion of the Coal Measures limestones occurring in adjacent portions of Illinois.

FRESH-WATER MARLS OF QUATERNARY AGE.

A very detailed report on "The lakes of northern Indiana and their associated marl deposits," by W. S. Blatchley and G. H. Ashley, appeared on pages 31–321 of the Twenty-fifth Annual Report Indiana Department Geology and Natural Resources. In this report all the known marl deposits in the State are separately described and detailed maps of the deposits are given. The following data are abstracted from this report:

DISTRIBUTION.

Marl deposits of sufficient size to justify the erection of Portland-cement plants occur in Indiana only in the three northern tiers of counties. The largest of these deposits, so far as area is concerned, is in Lake Wawasee, which contains about 1,700 acres, while the thickest deposit (45 feet) is reported from Turkey Lake, Lagrange County.

A deposit of marl covering 160 acres and 10 feet thick will supply for thirty years a cement plant producing 500 barrels a day. Thirty-three deposits of this size or greater are described in the report. The names and locations of the lakes containing these workable deposits are as follows:

Marl deposits in Indiana.

1. Hog Lake, Steuben County, 2 miles west of the village of Jamestown, Jamestown Township.
2. Lime Lake, Steuben County, 1 mile northwest of Orland (Mill Grove Township).
3. Clear Lake, Steuben County, in secs. 19 and 20, T. 38 N., R. 15 E. (Clear Lake Township).
4. Shallow and Deep lakes, Steuben County, secs. 6 and 7, T. 37 N., R. 12 E. (Jackson Township).
5. James Lake, Steuben County, 3 miles northwest of Angola.
6. Gage Lake, Steuben County, sec. 35, T. 38 N., R. 12 E.
7. Silver Lake, Steuben County, 4 miles west of Angola.
8. Shipshewana Lake, Lagrange County, three-fourths of a mile west of Shipshewana.
9. Cedar and Grass lakes, Lagrange County, 3 miles northeast of Lima.
10. Fish Lake, Lagrange County, 8 miles southeast of Lagrange.
11. Turkey Lake, Lagrange County, near Stroh.
12. Waldron Lake, Noble County, 2 miles west of Rome City.
13. Eagle Lake, Noble County, sec. 6, T. 34 N., R. 9 E.

14. Deer Lake, Noble County, sec. 25, T. 34 N., R. 8 E. (Sparta Township).
15. Crooked Lake, Whitley County, secs. 3 and 4, T. 32 N., R. 9 E. (Thorn Creek Township).
16. Loon Lake, Whitley County, 9 miles northwest of Columbia City.
17. Simonton Lake, Elkhart County, secs. 13, 14, 15, 16, and 17, T. 38 N., R. 5 E. (Osolo Township).
18. Indiana Lake, Elkhart County, northwest of Bristol.
19. Turkey Lake, Kosciusko County, near Syracuse.
20. Syracuse Lake, Kosciusko County, near Syracuse.
21. Milford Lake, Kosciusko County, 4 miles southeast of Milford.
22. Tippecanoe Lake, Kosciusko County, three-fourths of a mile southeast of Milford.
23. Barbee Lake, Kosciusko County, 3 miles southeast of Oswego.
24. Little Eagle Lake, Kosciusko County, 3½ miles northeast of Warsaw.
25. Center Lake, Kosciusko County, Warsaw.
26. Winona Lake, Kosciusko County, 1 mile southeast of Warsaw.
27. Manitou Lake, Fulton County, 1 mile southeast of Rochester.
28. Maxinkuckee Lake, Marshall County, secs. 15, 16, 21, 22, 27, 28, and 34, T. 32 N., R. 1 E.
29. Houghton Lake, Marshall County, secs. 7 and 18, T. 32 N., R. 1 E. (Union Township).
30. Chain Lake, St. Joseph County, 5 miles west of South Bend.
31. Du Chemin Lake, Laporte County, 11 miles northeast of Laporte.
32. Fish Lake, Laporte County, Fish Lake station.
33. North Judson Marsh, Starke County, 3½ miles west of North Judson.

A number of other marl deposits are described, which, though of sufficient size, have the larger part of their area covered by 10 feet or more of water, and are, therefore, not workable under present conditions.

COMPOSITION.

The composition of these marls is shown by the following table:

Analyses of Quaternary marls from Indiana.[a]

<table>
<tr><th>No.</th><th>Silica (SiO_2).</th><th>Alumina (Al_2O_3).</th><th>Iron oxide (Fe_2O_3).</th><th>Lime carbonate ($CaCO_3$).</th><th>Magnesium carbonate ($MgCO_3$).</th><th>Organic matter.</th><th>$CaSO_4$.</th></tr>
<tr><td>1</td><td>0.68</td><td>0.14</td><td>0.28</td><td>90.42</td><td>2.88</td><td>4.13</td><td>........</td></tr>
<tr><td>2</td><td>1.08</td><td>........</td><td>1.16</td><td>86.00</td><td>9.42</td><td>2.32</td><td>........</td></tr>
<tr><td>3</td><td>.47</td><td>.04</td><td>.12</td><td>93.29</td><td>2.67</td><td>1.56</td><td>........</td></tr>
<tr><td>4</td><td>1.16</td><td>........</td><td>.29</td><td>92.41</td><td>2.38</td><td>1.97</td><td>0.15</td></tr>
<tr><td>5</td><td>4.52</td><td>........</td><td>1.34</td><td>84.00</td><td>6.46</td><td>3.68</td><td>........</td></tr>
<tr><td>6</td><td>5.95</td><td>.41</td><td>.42</td><td>82.07</td><td>2.63</td><td>6.71</td><td>.22</td></tr>
<tr><td>7</td><td>7.94</td><td colspan="2">.64</td><td>82.89</td><td>2.04</td><td>3.67</td><td>........</td></tr>
<tr><td>8</td><td>1.42</td><td colspan="2">.88</td><td>88.21</td><td>4.78</td><td>2.58</td><td>........</td></tr>
<tr><td>9</td><td>1.78</td><td colspan="2">1.21</td><td>88.49</td><td>2.71</td><td>4.23</td><td>1.58</td></tr>
<tr><td>10</td><td>2.00</td><td colspan="2">.53</td><td>92.35</td><td>3.54</td><td>2.12</td><td>........</td></tr>
<tr><td>11</td><td>4.52</td><td>.18</td><td>.30</td><td>84.24</td><td>2.85</td><td>5.02</td><td>........</td></tr>
</table>

[a] Twenty-fifth Ann. Rept. Indiana Dept. Geol. Nat. Res., p. 321. W. A. Noyes, analyst.

Analyses of Quaternary marls from Indiana—Continued.

No.	Silica. (SiO_2).	Alumina (Al_2O_3).	Iron oxide (Fe_2O_3).	Lime carbonate ($CaCO_3$).	Magnesium carbonate ($MgCO_3$).	Organic matter.	$CaSO_4$.
12	2.48	0.06	0.26	90.67	2.42	2.87	....
13	2.92	....	.29	91.02	2.28	2.10	....
14	4.61	.15	.35	84.75	2.84	5.69	....
15	6.39	.19	.30	87.65	2.60	2.88	....
16	5.67	.12	.33	85.02	3.85	3.21	0.17
17	6.40	.05	.33	85.38	3.50	3.15	.17
18	15.26	.09	.51	75.07	4.18	3.65	.11
19	2.02	.04	.20	89.22	2.73	4.15	....
20	.19	.05	.07	91.62	4.02	2.25	.14
21	3.10	.10	.20	87.92	2.64	4.18	.23
22	.82	....	.08	91.30	2.90	3.88	.22
23	2.06	.45	.74	89.92	2.46	4.51	....

1. Hog Lake, Steuben County.
2. Lime Lake, Steuben County.
3. Deep Lake, Steuben County.
4. James Lake, Steuben County
5. Silver Lake, Steuben County.
6. Loon Lake, Whitley County.
7. Mud Lake, Elkhart County.
8. Cooley Lake, Elkhart County.
9. Syracuse Lake, Kosciusko County.
10. Dewart Lake, Kosciusko County.
11. Dewart Lake, Kosciusko County.
12. Tippecanoe Lake, Kosciusko County.
13. Tippecanoe Lake, Kosciusko County.
14. Little Eagle Lake, Kosciusko County.
15. Manitou Lake, Fulton County.
16. Maxinkuckee Lake, Marshall County.
17. Maxinkuckee Lake, Marshall County.
18. Maxinkuckee Lake, Marshall County.
19. Houghton and Moore lakes, Marshall County.
20. Notre Dame Lake, St. Joseph County.
21. Chain and Bass lakes, St. Joseph County.
22. Kankakee Marsh, St. Joseph County.
23. North Judson Marsh, Starke County.

PORTLAND-CEMENT INDUSTRY IN INDIANA.

Three Portland cement plants are now in operation in Indiana. These are the plants of the Sandusky Portland Cement Company, at Syracuse, the Wabash Portland Cement Company, at Stroh, and the Lehigh Portland Cement Company, at Mitchell. Of these, the first two mentioned use a mixture of marl and clay, while the plant last named uses hard limestone and clay.

Analyses of the materials used at these plants and of their product follow:

Analyses of raw materials and cement from Syracuse, Ind.

	1.	2.	3.	4.
Silica (SiO_2)	1.74	1.78	55.27	22.06
Alumina (Al_2O_3)	0.90	1.21	10.20	4.80
Iron oxide (Fe_2O_3)	0.28		3.40	1.66
Lime (CaO)	49.84	49.55	9.12	65.44
Magnesia (MgO)	1.75	1.29	5.73	3.82
Sulphur trioxide (SO_3)	1.12	([a])	n. d.	0.90
Carbon dioxide (CO_2)	46.01	40.36	n. d.	....
Water		4.23	n. d.	....
Organic	n. d.		n. d.	....

[a] $CaSO_4$, 1.58 per cent.

1. Marl. Twenty-fifth Ann. Rept. Indiana Dept. Geol., p. 28.
2. Marl. Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 6, p. 493.
3. Clay. Twenty-fifth Ann. Rept. Indiana Dept. Geol., p. 28.
4. Cement. Twenty-fifth Ann. Rept. Indiana Dept. Geol., p. 28.

Analyses of raw materials and cement from Stroh, Ind.

	1.	2.	3.	4.	5.	6.
Silica (SiO_2)	0.85	0.66	61.70	57.74	56.74	21.78
Alumina (Al_2O_3)	0.86	0.62	18.00	17.76	19.43	7.31
Iron oxide (Fe_2O_3)					4.83	2.65
Lime (CaO)	51.04	53.17	8.40	7.80	7.27	62.35
Magnesia (MgO)	1.31	0.47	2.91	3.52	3.05	2.88
Alkalies (K_2O, Na_2O)	n. d.	n. d.	n. d.	n. d.	n. d.	0.47
Sulphur trioxide (SO_3)	n. d.	n. d.	n. d.	n. d.	n. d.	1.78
Carbon dioxide (CO_2)	40.10	42.35	13.30	12.30	10.39	0.23
Water	n. d.	....				0.55
Organic	n. d.	2.53	....	....	....	....

1. Marl. W. R. Oglesby, analyst. Twenty-fifth Ann. Rept. Indiana Dept. Geol., p. 112.
2. Marl. Analysis given by Wabash Portland Cement Company, 1904.
3-4. Clay. Analysis given by Wabash Portland Cement Company, 1904.
5. Clay. W. R. Oglesby, analyst. Twenty-fifth Ann. Rept. Indiana Dept. Geol., p 112.
6. Cement. W. R. Oglesby, analyst. Twenty-fifth Ann. Rept. Indiana Dept. Geol., p. 28.

Analyses of raw materials for cement from Mitchell, Ind.

	1.	2.
Silica (SiO_2)	0.74	59.64
Alumina (Al_2O_3)	.13	[a] 19.14
Iron oxide (Fe_2O_3)		7.59
Lime (CaO)	52.49	.26
Magnesia (MgO)	1.87	2.31
Alkalies (K_2O, Na_2O)	n. d.	4.33
Carbon dioxide (CO_2)	43.68	.35
Water		4.36

[a] With TiO_2, 1.05 per cent.

1. Limestone. F. W. Clarke, analyst. Specimen collected by E. C. Eckel.
2. Shale. Twenty-sixth Ann. Rept. Indiana Dept. Geology, p. 276.

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The following papers relate to the raw materials or the manufacture of Portland cement in Indiana:

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BLATCHLEY, W. S. Clays and clay industries of northwestern Indiana. Twenty-second Ann. Rept. Indiana Dept. Geology, pp. 105–153. 1898.

BLATCHLEY, W. S. Portland cement (in Indiana). Twenty-fifth Ann. Rept. Indiana Dept. Geology, pp. 1–30. 1901.

BLATCHLEY, W. S. Oolite and oolitic stone for Portland cement manufacture. Twenty-fifth Ann. Rept. Indiana Dept. Geology, pp. 322–330. 1901.

BLATCHLEY, W. S., and ASHLEY, G. H. The lakes of northern Indiana and their associated marl deposits. Twenty-fifth Ann. Rept. Indiana Dept. Geology, pp. 31–321. 1901.

HOPKINS, T. C., and SIEBENTHAL, C. E. The Bedford white limestone of Indiana. Twenty-first Ann. Rept. Indiana Dept. Geology, pp. 291–427. 1897.

LATHBURY, B. B., and SPACKMAN, H. S. The Wabash Portland Cement Company, Stroh, Ind. The Rotary Kiln, pp. 128–133. 1902.

SIEBENTHAL, C. E. The Bedford oolitic limestone (Indiana). Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 6, pp. 292–296.

PORTLAND-CEMENT RESOURCES OF INDIAN TERRITORY.

By J. A. TAFF.

Limestones of several different ages occur in Indian Territory, and it is probable that most of them would be suitable for cement materials. No complete analyses, however, are available.

CAMBRIAN, ORDOVICIAN, AND SILURIAN LIMESTONES.

A large part of the Arbuckle Mountains in Indian Territory and of the northern foothills of the Wichita Mountains in southern Oklahoma are composed of a great section of Cambrian, Ordovician, and Silurian limestones,[a] having a total thickness of nearly 8,000 feet. There are three distinct limestone formations in this section, separated by deposits chiefly of shale.

ARBUCKLE LIMESTONE.

The lowest of these, known as the Arbuckle limestone, consists of limestone and dolomite of Cambro-Ordovician age 4,000 to 6,000 feet thick. Samples from the lower part and from the top downward 600 or 700 feet were tested for magnesia and lime and showed a very small percentage of magnesia. Beds 2,500 feet below the top contain a small amount of magnesia. Probably 2,000 feet of massive beds in the central part of the formation are dolomitic. A sample from approximately the middle of the formation yielded 29.4 per cent of lime and 19.2 per cent of magnesia, showing it to be a nearly normal dolomite. A sample from the lower part of this dolomitic zone showed contents of 33.1 per cent of lime and 14.3 per cent of magnesia. The Arbuckle limestone outcrops over more than three-fourths of the surface of the central part of the Arbuckle Mountain district, inclosing pre-Cambrian granite and granite-porphyry. Almost all of the limestones of the Wichita Mountains belong to this formation, which is fine-textured and generally hard.

VIOLA FORMATION.

An Ordovician limestone, 500 to 700 feet thick, known as the Viola formation, outcrops in a belt in the border of the Arbuckle Mountains and in small areas in the central part. It makes three small hills near Rainy Mountain Mission, in the Wichita Mountains. This formation is of limestone, with the exception of local deposits of chert. Chemical tests of samples from this limestone in the Arbuckle Mountains show it to contain very little magnesia. It is fine-textured and generally hard.

SYLVAN SHALE.

Above the Viola limestones is a deposit of greenish clay 50 to 300 feet in thickness, known as the Sylvan shale. This clay outcrops in narrow belts and has a wide distribution in the Arbuckle Mountains, but in the Wichita Mountains both it and the Hunton are concealed by Permian deposits.

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[a] These limestones are described in detail in the Atoka and Tishomingo folios Nos. 79 and 98. Also in the Geology of the Arbuckle and Wichita Mountains: Prof. Paper U. S. Geol. Survey, No. 31.

HUNTON LIMESTONES.

Separated from the Viola limestone by about 150 to 300 feet of clay shale is a Silurian formation having an average thickness of about 200 feet. This formation varies in physical character and in composition through its section. A massive bed at the base is in places almost pure limestone and is white, while in others it is in large part silicified. In the central part beds of clay and marl are interstratified with the limestone. Samples of limestone from the lower part of these beds contain a small amount of magnesia. Toward the top the limestone is white to light yellow and becomes more massive. Some of the layers near the top, however, contain local segregations of chert. In the reports above cited this formation is known as the Hunton limestone. Like the Viola limestone, it outcrops around the borders of Arbuckle Mountains in a narrow belt, besides occurring in many small areas in the central part.

CARBONIFEROUS LIMESTONES.

In northern Indian Territory are a few belts of Carboniferous limestones—continuations of the areas which are so important in Kansas. These limestones thin out and disappear to the south, however, and are probably of workable thickness only in the Cherokee Nation. Other formations of middle Carboniferous age occur in the eastern part of the Cherokee Nation and extend into Arkansas north of the Boston Mountains. These limestones are thin bedded, and with them are associated deposits of blue to black clay shales. Analyses of some of the beds from their eastern extension in Arkansas show only a trace or a fraction of a per cent of magnesia.

In central Choctaw Nation and along the southern edge of the coal field, is a long lentil of Carboniferous limestone of the same age and character as the limestones in eastern Cherokee Nation. In the central part of the exposure many of the beds are massive and the formation attains a thickness of nearly 300 feet. The eastern end of these exposures extends nearly to the Arkansas line on the north flank of the Ouachita Mountains, while the west end is in the edge of the Chickasaw Nation, against the Arbuckle Mountains. Judging from physical characters this limestone is essentially the same in quality as limestones above described in eastern Indian Territory and Northern Arkansas.

CRETACEOUS LIMESTONES.

Cretaceous limestones occur in the southern part of the Territory, in several distinct formations associated with the limy clays. These limestones are mostly soft, thin bedded, and are of various shades,

ranging from light blue through cream to white. The lowest limestone bed is, however, massive, white, and generally homogeneous. These formations continue southward in unbroken exposures from Red River, and, judging from analyses of very similar beds occurring in Texas, are probably low in magnesia.

PORTLAND-CEMENT RESOURCES OF IOWA.

By H. Foster Bain.

It has already been shown that materials capable of furnishing the silica and alumina necessary to the manufacture of Portland cement are widespread, and that the location of new plants is apt to be determined by the presence of suitable calcareous deposits and favorable industrial conditions. Iowa affords no exception to these general rules. In practically all parts of the State are shales or clays which might, if necessary, be used as one of the constituents of a cement mixture. The indurated rocks from the Ordovician to the Cretaceous afford shales of wide distribution and excellent character. The surface formations supplement these resources with loess, alluvium, and certain minor bodies of water-laid clay of glacial derivation. Material suitable for use in the manufacture of Portland cement can be found at almost every point in the State (see Pl. V).

The calcareous constituent of cements may be derived from marls, chalk, and limestone. All these occur within the State, though they are of very unequal importance.

CALCAREOUS MARLS.

Marl occurs in lakes which are particularly characteristic of the area covered by the Wisconsin drift. The north-central portion of Iowa is covered by drift of Wisconsin age,[a] and is dotted with small shallow lakes resembling in appearance and genesis those of Michigan. From time to time small amounts of marl have been reported from this area, and while so far no bodies of commercial importance have been located it is not impossible that such may be found.

CHALK DEPOSITS.

DISTRIBUTION.

The Cretaceous deposits which cover the western third of Iowa include important bodies of chalk. With but two exceptions, both of which are unimportant, outcrops of the chalk beds are confined to the valley of the Big Sioux River between Sioux City and Hawarden. The chalk beds received some attention in the course of the early geo-

[a] See Pl. II, Iowa Geol. Surv., vol. 11, 1900.

logical surveys of the region, and have been recently restudied by Calvin,[a] Bain,[b] and Wilder.[c]

The chalk forms prominent bluffs at intervals and may be well seen near Westfield, Akron, and Hawarden. It was referred to the Niobrara formation until Wilder discovered fossils characteristic of the Benton in the shale above. This proves that the Iowa chalk is the equivalent of the "Oyster Shell Rim" of the Black Hills or the Graneros limestone.

THICKNESS.

A thickness of 20 to 30 feet is ordinarily seen in individual exposures, but a total thickness of 50 feet is probably present. A generalized section may be given as follows:

Section of chalk beds.

	Feet.
1. Chalk	4-6
2. Limestone, soft, splitting into thin slabs and crowded with shells of *Inoceramus*	12
3. Chalk	12

COMPOSITION.

The interbanding of thin-bedded limestone with the chalk, as shown in the foregoing section, is quite characteristic. Both materials are soft and grind easily. Almost no magnesia is present, as is shown by the following analyses, and in some instances the chalk beds themselves carry enough or more than enough clay to make a good cement mixture. In all cases excellent clays occur immediately above or below. The clays are now being used at Sioux City and elsewhere in the manufacture of a wide variety of clay products.

Analyses of Iowa chalks.

	1	2	3
Silica (SiO_2) and insoluble	22.70	....	....
Iron oxide and alumina (Fe_2O_3 and Al_2O_3)	6.68	....	....
Calcium carbonate ($CaCO_3$)	64.30	83.70	94.39
Magnesium carbonate ($MgCO_3$)	5.38	2.48	.70
Water	....	.08	.06

1. Chalk rock, Hawarden, Iowa. Newberry, analyst.
2. Chalk rock, Westfield, Iowa. Weems, analyst.
3. Chalk rock, Lemars, Iowa. Weems, analyst.

[a] Calvin, S., Cretaceous deposits of Woodbury and Plymouth counties, etc.: Iowa Geol. Survey, vol. 1, 1893, pp. 147-161.

[b] Bain, H. F., Cretaceous deposits of the Sioux Valley: Iowa Geol. Survey, vol. 3, 1895, pp. 101-114; Geology of Woodbury County, ibid, vol. 5, 1896, pp. 273-275, 295-296; Geology of Plymouth County, ibid, vol. 8, 1898, pp. 354-360.

[c] Wilder, F. A., Geology of Lyon and Sioux counties: Iowa Geol. Survey, vol. 10, 1900, pp. 111-115, 151-152.

It is evident that materials suitable for the manufacture of cement are available, and this conclusion is confirmed by the fact that at Yankton, S. Dak., a plant has for many years been in operation in which similar beds belonging to the Niobrara are used. Furthermore, in tests carried on at Sioux City cement has been made experimentally from the local material.[a]

LIMESTONES.

Nonmagnesian limestones are found in Iowa in the Ordovician, Devonian, and Carboniferous. The limestones of the Cambrian and Silurian are without important exception highly magnesian. Those of the Ordovician are predominantly magnesian, though an exception occurs in the case of the beds which it has been customary to map and discuss under the name Trenton. In eastern Iowa the dolomites and magnesian limestones have heretofore attracted more attention than the nonmagnesian rocks, and flourishing lime and building stone industries have been founded upon them. Limestone of one class or the other occurs in all of the eastern and most of the southern counties. In the northwest the covering of Cretaceous and Pleistocene deposits limits the outcrops to a few deep stream valleys. The general distribution of the geologic formations of the State is shown on Pl. V. For details of localites the reader is referred to the various county reports of the Iowa Geological Survey cited in this text. The transportation facilities available at each point may be best learned from the large map of the State published and distributed gratuitously by the railway commissioners.

ORDOVICIAN LIMESTONES.

DISTRIBUTION.

Below the Devonian but one limestone outcrops in Iowa which is at all suitable for Portland cement manufacture. It is known as the Trenton, and occupies portions of Dubuque, Clayton, Fayette, Winneshiek and Allamakee counties.[b] Under this name has been mapped an aggregate of nonmagnesian limestones and thin shales, varying in thickness from 15 to 350 feet. The variation in thickness is an expression of the fact that the difference between the Galena and Trenton is lithologic and not formational. It is probable that in the future the division will be made upon some other basis, but for present purposes the lithologic difference is the important one. The strata included on this basis within the Trenton are in the main either non-

[a] Lonsdale, E. H., Proc. Iowa Acad. Sci., vol. 2, 1895, p. 173.

[b] Reports on the geology of Fayette, Winneshiek, and Clayton counties are now in preparation. For the geology of Allamakee County see Iowa Geol. Survey, vol. 4, pp. 35-120; for Dubuque County see ibid, vol. 10, pp. 379-651.

magnesian or only slightly magnesian. In composition as in geologic position they are almost exactly equivalent to the famous cement rock of the Lehigh Valley, from which 60 per cent of the Portland cement of the United States now comes.

Excellent exposures of the Trenton occur along the Mississippi River and its tributaries in the counties named above. At Specht Ferry, in Dubuque County, the following section was observed:

Specht Ferry section.

	Feet.
1. Thin-bedded brown domolite with shaly partings (Galena)	4
2. Thin-bedded, imperfectly dolomitized limestone, with fossil brachiopod shells only slightly changed; the limestone brown, earthy, noncrystalline, but evidently of the Galena type	3
3. Thick, earthy, imperfectly dolomitized beds (Galena)	3
4. Thin limestone beds with much shale in the partings; in part a true shale.	5
5. Limestone, bluish, rather coarse grained, with a few fossils	4
6. Limestone similar to above	3
7. Limestone similar to above	18
8. Shale, bluish or greenish, containing occasional thin beds or discontinuous flakes of limestone; the "Green shales" of the Minnesota geologists	12
9. Thin-bedded, bluish, rather coarse-grained limestone, weathering brownish in color	5
10. Limestone, in rather heavy layers, which range up to 15 inches in thickness; bluish on fresh fracture, but weathering to buff on exposure	5
11. Brittle, fine-grained blue limestone, very fossiliferous, breaking up on weathered surfaces into flexuous layers about 2 inches in thickness	20
12. Lower buff beds, exposed, about	8
13. Unexposed to level of water in river	45

COMPOSITION.

The "Green shale" No. 8 of the above section and the limestones above and below were sampled and analyzed by Mr. Lundteigen with the results given below:

Analyses of Trenton limestone from Specht Ferry section, Iowa.

	1	2	3	4.	5	6
Silica (SiO_2)	7.28	2.25	46.34	8.98	5.00	54.90
Alumina and iron oxide (Al_2O_3 and Fe_2O_3)	1.97	1.32	19.90	2.58	2.07	25.50
Lime (CaO)	46.93	49.66	10.27	41.32	50.22	.41
Magnesia (MgO)	2.58	3.24	2.13	5.80	.85	.30
Alkalies by difference					.76	9.55
Sulphur (S)	.39		.01	.00	.85	.24
Loss by ignition (H_2O, CO_2)	40.10	42.80	13.90	40.00	40.25	9.10
	99.25	99.27	92.55	98.68	100.00	100.00

1. Beds 5 and 6.
2. Bed No. 8.
3. Bed No. 9.
4. Bed No. 10.
5. General sample of limestone.
6. General sample of clay.

While the amount of magnesia in certain of these beds is higher than is desirable, there is still a large amount of rock available which is not higher in that element than that elsewhere used. It is probable that careful search would locate even better beds at the same horizon farther north.

DEVONIAN LIMESTONES.

There are in Iowa beds representative of both upper and middle Devonian. The former includes the State quarry beds in Johnson County[a] and the Sweetland shale in Muscatine County.[b] The larger portion of the Iowa section belongs to the middle Devonian, which may be divided into three formations—the Lime Creek, Cedar Valley, and Wapsipinnicon. In various counties these formations have been subdivided and individual members have been mapped. The Lime Creek and the Wapsipinnicon formations each include some shale and magnesian rock, but in general the Devonian limestones in Iowa are characteristically free from magnesia.

WAPSIPINNICON FORMATION.

DISTRIBUTION.

This formation was first discriminated by W. H. Norton, who has discussed it in considerable detail and has mapped various subdivisions belonging to it in Linn,[c] Cedar,[d] and Scott[e] counties. J. A. Udden has discriminated it in Muscatine County,[f] and Calvin has mapped certain members belonging to it in Johnson[g] and Buchanan[h] counties. Details of the development of the formation may be learned from the reports cited. In the northern portion of the State there is an overlap, so that the Wapsipinnicon is not represented.

COMPOSITION.

In general it may be stated that, while the formation includes some shale and some very pure limestones, the magnesia is apt to be found abundant in almost any section, and careful sampling will be necessary to determine the availability of the rock at any given point. The Fayette breccia, which forms one member of the Wapsipinnicon,

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[a] Calvin, S., Geology of Johnson County: Iowa Geol. Survey, vol. 7, pp. 33-104.
[b] Udden, J. A., Geology of Muscatine County: Idem, vol. 9, pp. 247-388.
[c] Geology of Linn County: Iowa Geol. Survey, vol. 4, pp. 121-195.
[d] Geology of Cedar County: Idem, vol. 11, pp. 279-396.
[e] Geology of Scott County: Idem, vol. 9, pp. 389-520.
[f] Geology of Muscatine County: Idem, vol. 9, pp. 248-388.
[g] Geology of Johnson County: Idem, vol. 7, pp. 33-116.
[h] Geology of Buchanan County: Idem, vol. 8, pp. 201-255.

includes near Rock Island a very pure limestone, as is shown by the following analysis:

Analysis of Fayette breccia.[a]

Insoluble	0.42
Iron (as carbonate)	.36
Lime carbonate ($CaCO_3$)	98.77
Loss, alkalies, etc	.45

Samples of the Otis and Kenwood beds from a railway cut 2 miles north of Cedar Rapids showed so much magnesia as to preclude the use of the rock.

CEDAR VALLEY LIMESTONE.

DISTRIBUTION.

The most important member of the Devonian of Iowa, as measured either by areal extent or thickness, is the Cedar Valley limestone. It extends from Muscatine County on the Mississippi to the Minnesota line in a broad belt trending northwest. It has an estimated maximum thickness of 300 feet and rests to the southeast on the Wapsipinnicon formation. To the northeast it comes by overlap to rest on the Maquoketa shale.[b] To the southwest it is in turn covered by rocks of the Mississippian series, while on the northwest the Lime Creek shales intervene between the latter and the Cedar Valley.

COMPOSITION.

In the southern portion of the area of outcrop the Cedar Valley limestone is characteristically a nonmagnesian limestone, which is usually fine grained and breaks with a sharp conchoidal fracture. This phase of the formation is excellently exposed in Johnson County, and the following analysis was made by George Steiger, in the laboratory of the United States Geological Survey, from an average sample representing the rock quarried at Iowa City. These quarries exposed a total thickness of about 50 feet.

Analysis of Devonian limestone at Iowa City.

Silica (SiO_2)	3.08
Alumina (Al_2O_3)	[c]1.24
Iron oxide (Fe_2O_3)	.73
Lime (CaO)	50.30
Magnesia (MgO)	2.22
Sulphur trioxide (SO_3)	.06

Toward the north the limestone becomes more magnesian, until in Howard County it is a massive dolomite which has been mistaken for

[a] Hall, Geology of Iowa, p. 372.
[b] Calvin, S., Geology of Howard County: Iowa Geol. Survey, vol 13, pp. 49–62.
[c] With the Al_2O_3 is included any TiO_2 or P_2O_5 present.

the Niagara. About midway the rock has been extensively quarried, at Independence and Waterloo, where it is a soft, easily crushed limestone, apparently nonmagnesian in character. At Waverly the rock is soft, thin bedded, and exposed to a total thickness of about 50 feet. Analysis of two separate beds, by Lundteigen, gave the following results:

Analyses of Devonian limestone at Waverly.

	1	2
Silica (SiO_2)	46.34	2.25
Alumina (Al_2O_3) Iron oxide (Fe_2O_3)	19.90	1.32
Lime (CaO)	10.27	49.66
Magnesia (MgO)	2.00	3.24
Sulphur trioxide (SO_3)	.01	.00
Loss on ignition	13.90	42.80
	92.42	99.27

Still farther north, in Mitchell County, the limestone has attracted attention because certain beds are lithographic.[a] The following analysis, made by Mr. A. B. Hoen, suggests that at least some of the stone is sufficiently free from magnesia to be suitable for cement material.

Analysis of Devonian limestone, Mitchell County.

Silica (SiO_2)	0.78
Alumina (Al_2O_3)	.12
Lime (CaO)	54.91
Magnesia (MgO)	.07
Soda (Na_2O)	.18
Potash (K_2O)	.11
Carbon dioxide (CO_2)	43.16
Water (H_2O)	.35

There are a number of fine exposures showing a thickness of 10 to 15 feet of the nonmagnesian beds. Not all of this rock is free from cracks and crystals, but it is all similar in composition to the sample analyzed. At the Gable and other quarries there is practically no stripping, while in the vicinity is an abundance of loess clay.

LIME CREEK SHALES.

DISTRIBUTION.

The uppermost member of the Devonian section of Iowa is well displayed in Cerro Gordo County, and has been discussed and mapped in

[a] Iowa Geol. Survey, vol., 13, pp. 292–352.

Calvin's report on that area.[a] He gives the following general section of the formations:

General section of the Lime Creek shales.

	Feet.
1. Calcareous beds, light gray in color	20
2. Magnesian shales and argillaceous dolomites	30
3. Limestone with slender Idiostroma	4
4. Fossiliferous calcareous shales	20
5. Yellow nonfossiliferous shales	10
6. Blue nonfossiliferous shales	40

Nos. 4, 5, and 6 of this section make up the Hackberry member of the formation, while the remaining beds represent the Owen beds.

COMPOSITION.

The shales constituting the lower portion of the foregoing section are used at Mason City for the manufacture of clay goods and are represented in the following analysis made by G. E. Patrick.

Analysis of Lime Creek clay at Mason City.

Silica (SiO_2)	54.64
Alumina (Al_2O_3)	14.62
Iron oxide (calculated as Fe_2O_3)	5.69
Maganese oxide (calculated as MnO)	.76
Lime (CaO)	5.16
Magnesia (MgO)	2.90
Soda (Na_2O)	1.12
Potash (K_2O)	4.77
Carbon dioxide (CO_2)	4.80
Hygroscopic water (expelled at 100° C.)	.85
Combined water (expelled by ignition)	3.74
Total	99.05

This analysis represents only the noncalcareous portion. The beds above contain considerable lime, as noted in the section given. In the vicinity of Mason City, where these beds outcrop, there are extensive exposures of the nonmagnesian beds of the underlying Cedar Valley, and it should be possible to combine the two to advantage.

CARBONIFEROUS LIMESTONES.

Carboniferous rocks underlie a large portion of Iowa. They include limestones, sandstones, shales, and coals. The limestones are very rarely magnesian, and because of this fact, as well as their excellent situation with reference to fuel and transportation facilities, it seems not improbable that time will see the development of a considerable cement industry based upon them.

[a] Geology of Cerro Gordo County: Iowa Geol. Survey, vol. 7, pp. 117-192.

Of the three series into which the Carboniferous has been divided, two—the Mississippian and the Pennsylvanian—are represented in this State. The Mississippian may be divided into the Kinderhook, Osage, and St. Louis, each containing important limestone beds. The Pennsylvanian includes the Des Moines formation (lower Coal Measures) and the Missourian (upper Coal Measures). The lower Coal Measures includes most of the coal beds worked in the State, but very little limestone. The formation outcrops in a broad belt between the limestones of the Mississippian series to the east and the calcareous shales and thin limestones of the Missourian formation.

The general distribution of the Mississippian, Des Moines, and Missourian beds is shown on the accompanying general map. The details as to character, thickness, etc., in any area may be learned in the appropriate county reports.[a]

KINDERHOOK LIMESTONE.

DISTRIBUTION.

The Kinderhook forms the lowermost division of the Carboniferous of this State. It consists for the most part of a soft argillaceous shale, which is exposed to a thickness of 60 feet at Burlington.[b] Above the shale are about 50 feet of sandstone and limestone belonging also to the Kinderhook. In general, the beds are not well exposed, and in the southern area of outcrop are not likely to be of importance in cement manufacture, except as a source of clay to be mixed with the overlying Burlington limestones. Farther north, in Marshall County, there is an extensive development of limestone. The rock is quarried at Le Grande.

COMPOSITION.

The following analyses, by G. E. Patrick, indicate that a considerable portion of the Kinderhook limestone is suitable for cement manufacture.

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[a] Reports upon counties in which the Carboniferous rocks are important will be found in the volumes of the Iowa geological survey, as follows:

Appanoose, 5, 361–438.
Boone, 5, 175–240.
Dallas, 8, 51–118.
Decatur, 8, 255–338.
Des Moines, 3, 409–492.
Fremont and Mills, 13, 123–183.
Guthrie, 7, 413–488.
Hardin, 10, 241–314.
Henry, 12, 237–302.
Humboldt, 9, 109–154.
Jefferson, 12, 355–438.
Keokuk, 4, 255–312.
Lee, 3, 305–408.
Louisa, 11, 55–126.
Madison, 7, 489–540.
Mahaska, 4, 313–380.
Marion, 11, 127–198.
Marshall, 7, 197–262.
Mills and Fremont, 13, 123–183.
Monroe, 13, 353–433.
Montgomery, 4, 381–452.
Page, 11, 397–460.
Polk, 7, 263–412.
Pottawattamie, 11, 199–278.
Story, 9, 155–246.
Van Buren, 4, 197–254.
Wapello, 12, 439–499.
Warren, 5, 301–360.
Washington, 5, 113–174.
Webster, 12, 62–191.

[b] Weller, Stuart, Iowa Geol. Survey, vol. 10, p. 65.

Analysis of Kinderhook limestone from Le Grande, Iowa.

	1	2	3	4
Silica (SiO_2) and insoluble	0.77	0.96	1.24	1.22
Alumina (Al_2O_3)	.05	.07	.18	.14
Iron oxide (Fe_2O_3)			.15	.26
Iron (FeO)	.09	.27	.09	.09
Manganese oxide (calculated as MnO)		.08		Trace.
Lime (CaO)	55.05	54.85	50.56	50.42
Magnesia (MgO)	.28	.28	3.70	3.96
Carbon dioxide (CO_2)	43.62	43.30	43.79	43.85
Hygroscopic water (loss at 100° C.)	.03	.09	.06	.04
Combined water (expelled by ignition)	.13	.21	.15	.12
Phosphoric acid			Trace.	
	100.02	100.11	99.92	100.10

PROBABLE COMBINATIONS.

	1	2	3	4
Silica and silicates Iron, alumina, oxides, etc	0.95	1.37	1.74	1.72
Calcium carbonate ($CaCO_3$)	98.30	97.95	90.28	90.04
Magnesium carbonate ($MgCO_3$)	.59	.38	7.77	8.08
Water (H_2O)	.16	.30	.21	.16
	100.00	100.00	100.00	100.00

1. Fine-grained oolite.
2. Blue limestone.
3. Iowa Caenstone.
4. Stratified limestone.

Associated with these beds are certain others which are more magnesian, but which happen to be in demand as building stone. Possibly a combination of industries could be based on this association. In Hardin County there is a considerable thickness of the rocks with some associated shale. Still farther to the north and west the Kinderhook outcrops, but without exposing any great thickness. While much of the Kinderhook limestone is magnesian, it is believed that in localities where other conditions are favorable, the formation warrants prospecting and testing.

OSAGE FORMATION.

DISTRIBUTION.

The Osage includes beds which have been widely known as the Keokuk and Burlington limestones. The formation consists for the most part of coarse crinoidal limestone, white, nonmagnesian, and with chert in nodules along bedding planes. The limestone, in the

upper portion especially, is associated with abundant argillaceous shale, and often outcrops in steep bluffs, at the foot of which the shales of the Kinderhook are available. The beds are best exposed in Lee and Des Moines counties, but occupy portions of Louisa, Washington, Henry, and other counties in the southeast part of the State.

At Burlington, in the south bank of Cascade Hollow, the following section was measured by Mr. T. E. Savage.

Cascade Hollow section.

	Feet.
1. Fine-grained, homogeneous soil material without pebbles, dark-colored above, grading down to yellow below	4
2. Clay with pebbles and small bowlders of granite and greenstone, reddish brown	6
3. Limestone, much decayed, in layers one 1 to 4 inches thick, numerous chert nodules	5
4. Chert	$\frac{2}{3}$
5. Limestone, crinoidal, coarse-grained, layers 4 to 8 inches thick	4
6. Limestone, crinoidal, with chert nodules	1
7. Limestone, coarse, crinoidal; at places massive, at others weathering into layers 3 inches to 1 foot thick, containing numerous fossils	10

COMPOSITION.

An average sample of this limestone was analyzed by George Steiger in the laboratory of the United States Geological Survey with the following results:

Analysis of Burlington limestone.

Silica (SiO_2)	5.18
Alumina (Al_2O_3)[a] Iron oxide (Fe_2O_3)	.87
Lime (CaO)	52.16
Magnesia (MgO)	.40
Sulphur trioxide (SO_3)	.00

The beds outcropping at this point are thoroughly representative of the limestone of this formation. Greater thicknesses are exposed at other points, and the total thickness has been estimated to be about 250 feet.

ST. LOUIS LIMESTONE.

DISTRIBUTION.

The St. Louis is one of the most widely distributed formations in Iowa. It rests on the Osage and lies unconformably below the Des Moines formation. On account of its relation to the coal beds it has been carefully mapped and extensively studied. It includes three minor divisions, the Pella, the Verdi, and the Springvale beds. The Verdi and Springvale beds have limited areas of outcrop and are

[a] This figure includes any TiO_2 or P_2O_5 present.

usually not suitable in composition for cement manufacture. The Pella beds are more important. They outcrop widely and are, in composition, excellently adapted to cement manufacture. They fringe the productive Coal Measures on the east and occur as scattered inliers within the general area of outcrop of the coal beds. This results from the pronounced unconformity between the Des Moines and the St. Louis, hills of the limestone rising like islands above the lowest coal beds.

The Pella beds usually show an upper portion consisting of calcareous marl with some thin beds of limestone. This facies is ordinarily 8 to 10 feet thick. Below it are beds of fine-grained blue to gray limestone, breaking with clean conchoidal fracture, and usually thin-bedded. The rock is very rarely magnesian, and the analysis quoted below is quite representative. The sample was taken from the Chilton quarry at Ottumwa by Mr. T. E. Savage. The beds exposed at this quarry are noted in the following section:

Chilton quarry section.

	Feet.
1. Fine-grained, dark-colored, pebbleless soil	1
2. Clay, reddish brown, with pebbles	3
3. Sandstone, brown, iron-stained, mostly incoherent, but in places indurated (Des Moines)	10
4. Calcareous shale, weathering into small bits, very fossiliferous	3
5. Limestone, dense, fine-grained, gray	2½
6. Limestone, shaly, soft, weathering readily, similar to No. 4	2
7. Limestone, dense, fine-grained, gray	1½
8. Shale, calcareous	3
9. Limestone, hard, fine-grained, gray, fossiliferous	1⅛
10. Limestone, dense, bluish	1
11. Limestone, dense, finer-grained, bluish gray, in part massive, in part thin-bedded, fossiliferous	4
12. Limestone, hard, gray	1⅓
13. Limestone, dense, gray	1½

COMPOSITION.

An average sample of the limestone here was analyzed in the laboratory of the United States Geological Survey by George Steiger with the following results:

Analyses of St. Louis limestone at Ottumwa.

Silica (SiO_2)	6.83
Alumina (Al_2O_3)	[a] 2.12
Iron oxide (Fe_2O_3)	.54
Lime (CaO)	49.54
Magnesia (MgO)	.07
Sulphur trioxide (SO_3)	.13

[a] This figure includes any TiO_2 or P_2O_5 present.

Samples of limestone from Pella, Tracey, Oskaloosa, and Humboldt have also been analyzed, with the following results:

Analysis of Iowa limestones.

	1	2	3	4
Silica (SiO_2)	4.92	....	....	....
Insoluble	....	1.57	4.01	0.91
Alumina (Al_2O_3)	3.39	.49	.13	.48
Iron oxide (Fe_2O_3)		.17	.46	.73
Lime (CaO)	47.50	....	....	....
Lime carbonate ($CaCO_3$)	....	94.60	95.30	97.98
Magnesia (MgO)	.00	3.17	.00	....
Sulphur trioxide (SO_3)	2.09	....	....	....
Carbon dioxide (CO_2)	38.10			
Water (H_2O)		....	....	....

1. Limestone, Pella. Lundteigen, analyst.
2. Limestone, Tracy. Murray, analyst.
3. Limestone, Oskaloosa. Murray, analyst.
4. Limestone, Humboldt. Murray, analyst.

Analyses of limestone and interbedded shale from the mouth of Lizard Creek in Webster County were made by Mr. Lundteigen, with the following results:

Analysis of limestones and shale.

	$CaCO_3$.	$CaSO_4$.
1. Upper, limestone, 2 feet	88.75	0.28
2. Middle, shale, 2 feet	53.25	2.46
3. Bottom, limestone, 2½ feet	88.75	.17

A cement made from this material gave the following analysis, and on test showed satisfactory color, strength, and setting properties.

Analysis of Fort Dodge cement.

Silica (SiO_2)	25.52
Alumina and iron oxide (Al_2O_3 and Fe_2O_3)	8.80
Lime (CaO)	63.48
Magnesia (MgO)	1.19

The material from the Pella exposures has been made up into a cement which has good color, is sound on glass, sets very quickly, and has satisfactory strength. The results of these tests, together with the fact that limestone of the same age and character is being extensively used at St. Louis, Mo., makes it certain that this formation can be relied upon to furnish the calcareous element wherever other conditions are favorable to the establishment of cement plants.

DES MOINES FORMATION.

DISTRIBUTION.

The Des Moines (lower Coal Measures) contains very little limestone. Its principal importance in the present connection arises from the coal and clay which make up so large a portion of the formation. The clays and shales are extensively used in the brick-making industry. They are available over wide areas, and may prove of service in connection with limestones of the formations above and below.

COMPOSITION.

The following analyses are typical of these clays:

Analyses of Coal Measures shales and clays.

	1	2	3
Silica (SiO_2)	53.08	64.41	53.86
Alumina (Al_2O_3)	17.71	20.43	26.28
Iron oxide (Fe_2O_3)	8.64	5.88	4.32
Lime (CaO)	4.05	.34	.12
Magnesia (MgO)	.94	1.71	.43
Soda (Na_2O)	3.70	1.90	.43
Potash (K_2O)	1.25		2.52
Sulphur trioxide (SO_3)	....	....	1.22
Carbon dioxide (CO_2)	2.53	....	....
Water (H_2O), combined	6.77	3.93	3.02
Water (H_2O), free	....	1.27	....
Undetermined and ignitious	1.33	....	8.06

1. Brick clay, Fort Dodge.
2. Brick clay, Des Moines. C. O. Bates, analyst.
3. Brick clay, Ottumwa. J. B. Weems, analyst.

APPANOOSE BEDS.

Near the middle of the Des Moines formation are strata which have been called the Appanoose beds. These have been mapped and discussed in connection with the report on Appanoose County, and their outcropping edge is shown on the accompanying map (Pl. V). They include the Mystic or Centerville coal and certain associated shales and limestones. The latter are known locally, from their relations to the coal, as the "Bottom rock," "Cap rock," "Thirteen-foot limestone," and "Fifty-foot limestone." The limestone bed is thin, usually from 4 to 6 feet in thickness, but near Rathbun and Clarkdale it reaches a thickness of 10 to 15 feet. It is a soft limestone, easily crushed, and because

of its close association with clay and a very good coal bed is probably of value. Analyses show that it is practically free from magnesia and runs from 74 to 93 per cent in calcium carbonate. The following analysis, by Lundteigen, is representative.

Analysis of Fifty-foot rock, Rathbun.

Silica (SiO_2)	9.90
Alumina (Al_2O_3) Iron oxide (Fe_2O_3)	6.40
Magnesia (MgO)	Trace.
Lime carbonate ($CaCO_3$)	83.37

MISSOURIAN FORMATION.

DISTRIBUTION.

The southwestern portion of Iowa is underlain by the rocks of the Missourian formation or upper Coal Measures. In contrast with the lower Coal Measures or Des Moines formation, the Missourian includes considerably less sandstone and very little coal. The beds are mainly shales and limestones. The latter are almost entirely free from magnesia, are occasionally somewhat earthy, are usually free from chert, and are easily ground. They are accordingly well adapted to cement manufacture, and, indeed, the equivalent beds are now in use at Iola. Kans. The individual members of the Missourian formation have not been mapped in Iowa, though they are discussed in the county reports. The most important limestone lies at the base of the formation, and its outcrop is accordingly indicated on the accompanying map by the eastern edge of the formation. This limestone, which is variously known as the Winterset, Earlham, and Bethany, is discussed in some detail in the Madison County report.

The Bethany limestone in Madison County includes four separate ledges occurring in the following order and thickness: Fusulina, 25 feet; Winterset, 20 feet; Earlham, 21 feet; Fragmental, 10 feet. These ledges are separated by shale beds, usually 10 to 20 feet in thickness and in part calcareous. The rocks are quarried at various points, particularly Earlham, Winterset, and Peru, and the same ledges have been recognized as far south as Decatur County, on the Missouri boundary.

COMPOSITION.

Analyses of individual ledges at Peru, made by Lundteigen, show a lime content ranging from 60.50 to 83 per cent. A cement mixture made from them gave 75.50 per cent $CaCO_3$. At Earlham the following section was measured by Mr. T. E. Savage, and an analysis of an average mixed sample of the stone was made in the laboratory of the

United States Geological Survey by George Steiger. The results are given below:

Section of Robertson quarry, Earlham.

Number.		Feet.	Inches.
1	Dark-colored, fine-grained, pebbleless soil	1	......
2	Reddish bowlder clay with pebbles and quartzite fragments	1	6
3	Yellowish-colored, soft, shaly limestone, which disintegrates readily	4	......
4	Layer of very hard, light-gray, fine-grained limestone	......	7
5	Narrow layer of softer limestone with less perfectly comminuted fossil fragments	......	2
6	Ledge of hard, white limestone, fine-grained, separating in places into three or four uneven layers	3	......
7	Soft, calcareous shale which weathers rapidly into fine bits	......	4
8	Dense gray, fine-grained limestone; fossil fragments abundant but indistinct	......	6
9	Gray shale like No. 9	......	1½
10	Layer of hard gray limestone	......	2
11	Band of soft shale	......	1½
12	Dense, fine-grained, light-gray limestone, in places massive, again separating into two layers of about equal thickness	1	8
13	Shale, soft, gray in color, and quite calcareous	......	6
14	Layer of impure limestone, grayish yellow in color	......	2½
15	Band of soft, gray, calcareous shale	......	7
16	Ledge of hard, fine-grained, light-colored limestone, imperfectly separated into three uneven layers	1	3
17	Massive layer, separating in places into two uneven layers with shaly partings between them and such partings of shale separating No. 3 from No. 4 above and No. 2 below	1	4
18	Ledge of gray limestone	1	3
19	Layer of gray limestone	1	8

Analysis of Earlham limestone.

Silica (SiO_2)	10.92
Alumina (Al_2O_3)	[a] 1.77
Iron oxide (Fe_2O_3)	.60
Lime (CaO)	47.66
Magnesia (MgO)	.75
Sulphur trioxide (SO_3)	None.

The beds above the Bethany have not been as carefully studied, though they are apparently similar in composition and character. The next higher limestones, the Dekalb, yielded the following on partial analysis by J. B. Weems:

[a] This includes any P_2O_5 or TiO_2 present.

Analysis of Dekalb limestone.

Lime carbonate ($CaCO_3$)	91.96
Magnesium carbonate ($MgCO_3$)	1.99
Water (H_2O)	.07

ECONOMIC CONDITIONS.

AVAILABLE MATERIALS.

It is believed that the data presented bear out the assertion that there are many points in Iowa at which materials suitable for manufacture are available. The marls are not now known to be important and may never prove to be. Chalk suitable in all particulars may be found along Sioux River north of Sioux City. As this is a soft, easy-grinding material, it is a favorite among cement manufacturers. The question of the advisability of establishing a plant in this district must be determined by consideration of manufacturing costs, of market, and transportation facilities.

In regard to the limestones the following general considerations are important. Iowa is largely a drift-covered State, and within the broad areas shown upon the map as underlain by the various limestones there are really only a limited number of outcrops. Even where outcrops occur the overburden is in many cases so thick as to entail prohibitive stripping costs. The best situations are in the valleys, usually where some important tributary joins the main stream. Fortunately many of the railway lines follow valley routes.

The Trenton limestone, which occurs in the driftless area, is found usually in rather steep bluffs, a fact due to the resistant character of the dolomite usually found above it. As compared with the other limestones of the region, the Trenton is most likely to carry magnesia in excess; but it is, on the other hand, practically free from chert, is often somewhat earthy in composition, and is intimately associated with shale. As already noted, the similar and approximately equivalent beds in the Lehigh district of Pennsylvania and New Jersey are a very important source of cement material.

The Devonian limestones are in large measure free from both chert and magnesia, though outcrops in the northern part of the State need careful examination to make sure of the absence of the latter. As contrasted with both the Trenton and the Carboniferous limestones they are in the main harder, and this will to some extent influence the cost of grinding.

Of the Carboniferous limestones the Kinderhook is in most situations too magnesian and the Osage too full of chert for easy use, though it is probable that some suitable material can be found in each formation. The Pella beds of the St. Louis and the Winterset and other limestones of the Missourian are entirely suitable as regards

composition, freedom from chert, and grinding qualities. Equivalent beds are now in use in Missouri and Kansas. These limestones are, furthermore, excellently situated as regards fuel and clay. The Productive Coal Measures, Des Moines formation, outcrop in a broad belt between the two, and often the Pella beds and shales of the Des Moines occur in the same section. Where the shales are absent, loess, such as is elsewhere used, is nearly everywhere present.

FUEL.

The area of the Productive Coal Measures, Des Moines formation, is shown on the accompanying map. It will be seen that the coal mines are so situated as to afford cheap fuel to most of the limestone localities. This is important, since the fuel cost forms approximately 30 per cent of the total cost of manufacture. Iowa coal, while not of the highest grade, is still well adapted to cement manufacture. The following analyses indicate the approximate composition of a few of the beds. These analyses and tests were made at the Iowa State College of Agriculture, and are published in the report on Monroe County.[a]

Analyses of Iowa coals.

	1	2	3	4	5	6	7	8
Volatile combustible	42.32	37.79	37.98	45.62	46.06	36.94	35.11	18.23
Fixed combustible	46.31	54.85	47.98	50.29	46.89	54.20	51.91	75.08
Total combustible	89.13	92.64	85.96	95.91	92.95	91.14	87.02	93.31
Ash	10.13	7.36	14.04	4.09	7.05	8.86	12.77	6.69
Sulphur	4.10	3.29	5.90	2.74	2.81	2.86	3.02	.60
B. T. U	11,922	12,681	12,431	12,041	13,050	12,245	....	....

1. Average five Monroe County coals.
2. Centerville Block Coal Company, Appanoose County.
3. Corey Coal Company, Webster County.
4. Des Moines C. & M. Company, Polk County.
5. Whitebreast Fuel Company, Pekay, Mahaska County.
6. Carbon Coal Company, Willard, Wapello County.
7. Average 22 Illinois coals.
8. Pocahontas coal, Virginia.

In the above tables the Pocahontas coal is quoted for comparison, and the Illinois coals are noted, since, in event of the Trenton limestone being used, coal would probably be drawn from Illinois rather than Iowa. Many additional analyses will be found in the special report on the coal deposits forming Volume II of the reports of the Iowa Geological Survey, and some additional data in the Twenty-second Annual Report of the United States Geological Survey.[b]

[a] Iowa Geol. Survey, vol. 13, p. 414.

[b] The Western Interior coal field: Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 3, pp. 333–366.

TRANSPORTATION.

The relations to transportation lines are perhaps sufficiently indicated by the map (Pl. V). It may be noticed that there are several promising localities along the Mississippi where that river could be utilized directly and would, in addition, act as a regulator to railway lines. The main railway lines of Iowa run either east-west or southeast-northwest, and much of the freight originating in the State, aside from agricultural products, moves to the north and west.

Markets.—Any cement plant which may be established would find a ready market in the same direction. Iowa itself affords a very considerable market for cement, and an Iowa cement plant would have considerable advantage in reaching an important and growing market to the north and west.

PORTLAND-CEMENT RESOURCES OF KANSAS.[a]

PORTLAND-CEMENT MATERIALS.

Limestones of economic importance occur in Kansas in four different geologic groups, as follows: (1) Mississippian, (2) Coal Measures, (3) Permian, (4) Cretaceous.

Of these, the Coal Measures limestones are at present of most importance, and are the only ones now in use as Portland-cement materials. The Cretaceous chalky limestones would be valuable cement materials if fuel supply and markets were nearer. The limestones of the Permian are of little present or prospective importance; but those of the Mississippian are most promising.

MISSISSIPPIAN ("LOWER CARBONIFEROUS") LIMESTONES.

The Mississippian rocks of Kansas occur only in one small area in the extreme southeastern corner of the State, about 30 square miles in Cherokee County being covered by rocks of this age. The series is made up of limestones, with interbedded cherts, and a few beds of shale. The limestones are usually heavily bedded and low in magnesia.

The limestone quarries in the Lower Carboniferous are described by Haworth as follows:[b]

> In the southeastern part of the State a small amount of quarrying is done in the sub-Carboniferous limestone at and near Galena. This limestone is a highly crystalline one, very compact in character, light blue in color, and occurs in heavy layers, so that large dimension stone could be obtained from it were the quarries operated for that purpose. It is the same rock in every respect, both as to geologic age and general character, that is so extensively quarried at Carthage and other

[a]The data relative to the distribution and composition of Kansas limestones is quoted, in large part, from descriptions given in the "Mineral Resources of Kansas for 1897," a publication issued by the Kansas State Geological Survey.

[b]Mineral Resources of Kansas, 1897, pp. 73–74.

points in Missouri. From the Carthage quarries many thousands of dollars' worth of stone are shipped into Kansas, all of which might be supplied from the Kansas stone if quarries were worked as extensively as might be done. The quarries at Galena are operated to supply local demand, and that only for foundation material in buildings, although considerable dimension stone is shipped from Carthage into Galena for the larger buildings.

Years ago this same stone was quarried at Galena, at Lowell, and elsewhere for the production of lime. It is so abundant in quantity and so easily accessible along the hillsides that it is a great wonder more limekilns are not in operation. The same rock is quarried at different places in Missouri and burnt into lime, producing lime of a good quality, but no better than might be obtained from Kansas quarries.

Analyses of Mississippian limestones from Kansas.

	1	2
Silica (SiO_2)	0.32	[a] 8.00
Alumina (Al_2O_3)	.17	.69
Iron oxide (Fe_2O_3)	.20	
Lime carbonate ($CaCO_3$)	98.66	97.32
Magnesium carbonate ($MgCO_3$)	.73	.80

[a] Probably erroneous.

1. Quarry on Short Creek, near Spring River, Cherokee County. L. G. Eakins, analyst. Bull. U. S. Geol. Survey No. 78, p. 125.
2. Galena, Cherokee County. Mineral Resources of Kansas, 1897, p. 78.

PENNSYLVANIA ("COAL MEASURES") LIMESTONES.

The Coal Measures rocks of Kansas covers the three eastern tiers of counties and parts of the counties in the fourth tier. Though made up mostly of shales and sandstones, the series includes a number of beds of limestone. These limestones are of importance as Portland-cement materials because of their usual purity, their proximity to satisfactory shales and to transportation routes and, above all, because they occur, in many places in Kansas, in the vicinity of natural-gas fields.

Haworth describes the Coal Measures limestones as follows:[a]

To the northwest of Cherokee County many local quarries in heavy limestone formations have been operated, some of which are still operated in an irregular manner. The most extensive of these is the quarry at Iola, which has produced large quantities of dimension stone and sawed flagstone for local trade and for shipment to other points. The limestone at Iola exists in a layer nearly 40 feet thick, from which dimension blocks of any size or proportion desirable can be obtained.

Still farther to the northwest the next quarries are those along the banks of the Kansas River west of Kansas City, from which large quantities of stone are taken for ballast and for macadamizing streets. Near Kansas City a deposit of fragmentary material exists, from which large quantities have been shipped for making sidewalks, macadamizing streets, and similar purposes.

[a] Mineral Resources of Kansas, 1897, p. 74-75.

Other places furnish quantities of stone, the output of which would be greatly increased if the demand were sufficient to justify the extensive operation of quarries. Generally, however, it is principally a local demand, for which no statistics can be gathered, but which in the aggregate amounts to many thousands of dollars.

Still farther west a limestone exists which is remarkable in many of its properties, permitting it to be successfully quarried for all kinds of dimension stone wherever it comes to the surface. It is known commercially as the Cottonwood Falls limestone, because such large quantities have been shipped from Cottonwood Falls and Strong City to so many points within and without the State. The same rock has been quarried at a dozen or more places to the north of Cottonwood Falls, such as Eskridge, Alma, Manhattan, Beattie, and a number of other places. This limestone is not very thick, averaging from 5 to 8 feet, and generally consists of two individual layers, known in the markets as the "upper" and the "lower." The rock from the two layers differs slightly in quality, the lower one generally producing the best stone. Its most valuable properties are two—almost perfect uniformity of texture throughout, and the absence of vertical fissures. It is white or light cream in color, fine and noncrystalline in texture, and well filled with the little rice-grain-like invertebrate fossil, *Fusulina cylindrica*. The color is so uniform that when the stone is placed in a building the general color effect is very pleasing and satisfactory. The absence of vertical fissures and the uniformity of texture throughout make it possible to obtain dimension blocks of any size desired, which can be worked with perfect uniformity. These qualities make it by all odds the most desirable and therefore the most extensively used stone in the State. Large buildings are erected from it entirely, and many others partly constructed from the same rock. The different quarries, so widely separated, make it possible for a large community to use it without paying excessive freight.

From this Cottonwood Falls limestone the following important buildings are constructed: Snow Hall, and the stone trimmings of the main building, University of Kansas, Lawrence; the Methodist Episcopal Church, Lawrence; the Rock Island depot, Topeka; the Santa Fe depots at Ottawa, Wellington, and elsewhere; and a number of other depot buildings along the lines of the different railways in Kansas.

In addition to the above-mentioned uses, the different railroads in the State use the Cottonwood Falls limestone for bridge building and other construction purposes. This is true to so great an extent that many thousands of dollars' worth of dimension stone are annually supplied the different Kansas lines for use in this State and elsewhere, much of it being shipped outside of the State.

Analyses of Coal Measures limestones from Kansas.[a]

No.	Silica (SiO_2).	Alumina (Al_2O_3) and iron oxide (Fe_2O_3).	Lime carbonate ($CaCO_3$).	Magnesium carbonate ($MgCO_3$).	Sulphur trioxide (SO_3).
1	1.53	1.75	94.12	2.72	....
2	1.99	1.21	95.20	1.10	....
3	3.79	1.07	93.20	1.01	0.20
4	2.75	5.91	91.02	.14	....
5	2.63	1.76	94.10	.54	....
6	4.30	.81	92.76	.95	.23
7	.61	1.51	97.32	.32	.43

[a] From Mineral Resources of Kansas, 1897, pp. 77-78.

Analyses of Coal Measures limestones from Kansas—Continued.

No.	Silica (SiO_2).	Alumina (Al_2O_3) and iron oxide (Fe_2O_3).	Lime carbonate ($CaCO_3$).	Magnesium carbonate ($MgCO_3$).	Sulphur trioxide (SO_3).
8	11.83	5.53	81.91	1.56	0.05
9	8.57	3.62	84.72	1.75	.90
10	7.30	1.05	90.00	1.60	.03
11	3.53	1.07	94.18	1.16	....
12	2.29	1.79	95.02	.79	....
13	8.02	2.05	88.54	1.29	....
14	.66	2.13	93.49	3.04	.36
15	1.18	2.38	94.77	1.07	....
16	3.82	.77	94.21	1.30	....
17	3.94	1.20	93.61	1.20	....
18	4.79	1.18	93.30	1.26	....
19	1.18	3.09	92.71	2.64	....
20	6.98	1.04	90.01	1.66	....
21	8.00	1.35	90.00	.12	.02
22	5.91	2.47	89.88	1.11	.38
23	6.20	3.31	88.17	1.88	.28
24	12.97	3.06	78.46	1.16	2.32
25	17.49	4.09	69.07	3.06	.37
26	8.75	2.37	84.80	2.80	....
27	14.01	1.34	80.31	3.87	.78
28	13.89	4.29	80.10	1.00	.39
29	1.50	95	96.50	.74	....
30	1.35	1.32	96.09	1.00	....
31	2.44	.82	95.57	.80	....
32	16.15	1.91	79.25	1.80	....
33	11.97	3.59	81.98	1.20	.55
34	6.22	1.74	89.68	1.99	....
35	9.12	.70	88.55	1.25	....
36	10.37	2.49	84.53	2.35	....
37	3.27	2.61	92.50	1.62	....
38	6.80	2.60	88.03	2.04	.21

1, 2, 3. Humboldt, Allen County.
4, 5. Iola, Allen County.
6, 7. Garnett, Anderson County.
8. Horton, Brown County.
9. Cottonwood Falls, Chase County.
10. Strong City, Chase County.
11, 12, 13. Lawrence, Douglas County.
14. Moline, Elk County.
15, 16, 17, 18. Lane, Franklin County.
19. Greeley, Franklin County.
20. Winchester, Jefferson County.
21. Ottawa, Johnson County.
22, 23, 24. Lansing, Leavenworth County.
25. Soldiers' Home, Leavenworth County.
26, 27, 28. Beattie, Marshall County.
29, 30, 31. Fontana, Miami County.
32. Independence, Montgomery County.
33. Sabetha, Nemaha County.
34, 35, 36. Alma, Wabaunsee County.
37. McFarland, Wabaunsee County.
38. Yates Center, Woodson County.

PERMIAN LIMESTONES.

Permian rocks occur west of the Coal Measures and include a few beds of limestone, which are described briefly by Haworth:[a]

A few hundred feet above the Cottonwood Falls limestone are heavy beds of the Permian limestone, which are usually filled with flint nodules. These soft Permian limestones, carrying so much flint, are very serviceable for railroad ballast and are extensively quarried and crushed for this purpose at different places. The quarry near Strong City has probably yielded more ballast of this kind than any other one in the State, but extensive quarries are operated farther west along the Santa Fe at Florence and near Marion, and along the Rock Island at different points, all of which produce practically the same kind of stone.

Analyses of Permian limestones from Kansas.

	1	2	3	4	5	6
Silica (SiO_2)	5.04	13.60	3.34	5.27	4.25	5.51
Alumina (Al_2O_3)	.96	2.55	1.69	1.07	.85	1.24
Iron oxide (Fe_2O_3)				1.03		
Lime carbonate ($CaCO_3$)	93.32	76.16	93.98	89.93	94.06	91.50
Magnesium carbonate ($MgCO_3$)	1.06	7.63	.94	1.18	.62	1.62

1. Eldorado, Butler County. Mineral Resources of Kansas, 1897, p. 77.
2. Arkansas City, Cowley County. Ibid.
3. Cambridge, Cowley County. Ibid, p. 78.
4. Silverdale, Cowley County. C. Catlett, analyst. Bull. U. S. Geol. Survey No. 64, p. 46.
5. Winfield, Cowley County. Mineral Resources of Kansas, 1897, p. 77.
6. Marion County. Ibid.

CRETACEOUS LIMESTONES.

The chalk and chalky limestones of the Cretaceous occurring in western Kansas are as promising as those of Arkansas and Texas, but the quarries are at present handicapped by distance from fuel and from cement markets. Haworth describes the limestones as follows:[b]

In the central and west-central part of the State the Cretaceous limestones have been quarried to a great extent. They are generally spoken of locally as magnesian limestone, although such a term is entirely misapplied. A belt of country stretches across the State, by way of Beloit and Russell, throughout which a fine layer of limestone is quarried and broken into pieces suitable for fence posts. Travelers passing from east to west along almost any railroad line in the State can notice large fields and pastures fenced entirely by fastening the wire fencing to these stone posts, which are set in the ground similar to the way common wooden posts are used in ordinary fencing. The Cretaceous limestones also serve many structural purposes in all of the cities and villages within the Cretaceous area. The rock is so soft it can easily be sawed into blocks and worked with chisel and hammer much more rapidly than ordinary limestone. This, added to its property of materially hardening after quarried, greatly increases its value. None of it is what would be called a first-class building material, yet it is capable of being used in many ways,

[a] Mineral Resources of Kansas, 1897, p. 75.
[b] Ibid, pp. 75-76.

and furnishes a convenient and durable structural material for that part of the State, which prevents other stone from being shipped in. Here, as elsewhere, local demands are not so great now as they formerly were, but every year thousands of dollars' worth of the rock are quarried and used for various purposes, principally for supplying fence posts.

Analyses of Cretaceous limestones from Kansas.

	1	2
Silica (SiO_2)	4.81	5.06
Alumina (Al_2O_3)	3.07	2.08
Iron oxide (Fe_2O_3)		
Lime carbonate ($CaCO_3$)	90.63	91.30
Magnesium carbonate ($MgCO_3$)	.84	.87
Water	.08	.44

1. Coolidge, Hamilton County. Mineral Resources of Kansas, 1897, p. 78.
2. Jetmore, Hodgeman County. Ibid.

PORTLAND-CEMENT INDUSTRY IN KANSAS.

Two Portland-cement plants are now in operation at or near Iola, Allen County, while a third is in prospect, to be located at Independence, Montgomery County. Both of the present plants (as well as the one projected) use Carboniferous limestones and shales. While the materials are very satisfactory, there is nothing strikingly advantageous in their use. The particular advantage possessed by the Kansas plants is derived not from the use of especially good raw materials, though the limestones and shells are satisfactory enough, but from the fact that the plants are located in a natural-gas area and are therefore supplied with cheap fuel.

The materials used at the two plants now in operation give the following representative analyses:

Analyses of limestones and shales used for cement making in Kansas.

	1	2	3	4	5
Silica (SiO_2)	0.86	1.19	54.18	1.1	56.0
Alumina (Al_2O_3)		.95	19.17	1.8	22.1
Iron oxide (Fe_2O_3)	.29	1.28	6.11		
Lime (CaO)	55.74	53.13	7.05	51.7	8.0
Magnesia (MgO)	.51	1.36	1.89	2.0	1.5
Carbon dioxide (CO_2)	42.76	42.66	11.95	43.3	10.7
Water	.04				

1. Limestone from Iola, Kansas. H. N. Stokes, analyst. Bull. U. S. Geol. Survey No. 78, p. 124.
2. Limestone used by Iola Portland Cement Company.
3. Shale used by Iola Portland Cement Company.
4. Limestone used by Kansas Portland Cement Company.
5. Shale used by Kansas Portland Cement Company.

PORTLAND CEMENT RESOURCES OF KENTUCKY.[a]

Limestones prevailingly low in magnesia and otherwise satisfactory as cement materials occur in Kentucky in four different geologic groups. These groups, whose areal distribution in Kentucky is shown on the map forming Pl. VI, are as follows, beginning with the oldest:

1. Trenton limestone.
2. Cincinnati group limestones.
3. Mississippian or Lower Carboniferous limestone.
4. Pennsylvania or Coal Measures limestones.

TRENTON LIMESTONE.

The Trenton group occupies much of the counties of Franklin, Scott, Bourbon, Woodford, Fayette, Jessamine, and smaller portions of Boyle, Clark, Mercer, Owen, Henry, and Anderson. The limestones which make up most of this series are usually quite low in magnesia, while their range in lime carbonate is commonly from 90 to 95 per cent.

According to Mr. E. O. Ulrich the rocks in Kentucky that are referred to this group comprise an exposed thickness of about 700 feet of solid, chiefly nonmagnesian, limestone. The magnesian beds are practically confined to the lower 400 feet, and it is doubtful if these magnesian beds will reach an aggregate thickness of 150 feet. The series is equivalent to the Mohawkian of New York, to the limestones in Middle Tennessee included between the Murfreesboro and Catheys limestones (see Columbia folio), and, in a general way, to the "Trenton" (including Galena) of the Mississippi Valley.

In Kentucky State reports the series is divided, from below upward, into "Chazy," "Birdseye," and "Trenton". The first two are the same as the Stone River group in Tennessee and the High Bridge limestone of Campbell in the Richmond folio. The third embraces the recognizable equivalents of the Hermitage, Bigby, and Cathey limestones of middle Tennessee, and the Lexington limestone (= Hermitage and Bigby), Flanary chert, and lower part of Winchester limestone (together = Cathey) of Campbell.

[a] For most of the data presented in regard to Kentucky cement materials the writer is indebted to Mr. E. O. Ulrich, of the U. S. Geological Survey

Analyses of limestones from Trenton group, Kentucky.[a]

[R. Peter, analyst.]

	1	2	3	4	5	6	7	8	9
Silica (SiO_2)	5.92	2.38	2.18	2.08	6.94	1.88	5.18	1.58	2.18
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	3.28	3.98	2.42	.77	.12	2.70	1.53	.38	.63
Lime carbonate ($CaCO_3$)	85.56	91.48	92.73	95.38	89.63	90.72	91.33	95.68	94.75
Magnesium carbonate ($MgCO_3$)	3.57	1.04	.63	1.51	.88	4.61	.56	2.04	1.96
Alkalies (K_2O, Na_2O)	.88	.55	.51	.14	.52	.35	.77	.24	.26
Sulphur trioxide (SO_3)	.47	.32	.34	.58	.68	n.d.	.33	.17	.30

[a] From Kentucky Geol. Survey, Rept. A, pt. 2, pp. 123-124.

1. Clark County.
2. Fayette County.
3. Fayette County.
4. Franklin County.
5. Franklin County.
6. Mercer County.
7. Woodford County.
8. Fayette County.
9. Woodford County.

The proposed Portland cement plant at Mentor will use shaly limestone of Trenton age. This formation outcrops in a narrow strip along the Ohio River in Kenton and Campbell counties. Another proposed plant, below Ludlow, is to use the limestones (100 feet thick) capping the hills and the Eden shales beneath them. The slope of the hills, to a height of 250 feet or more, is composed of these shales. The Trenton limestone along Ohio River runs higher in silica than in central Kentucky, but $MgCO_3$ generally is less than 2 per cent.

CINCINNATI OR HUDSON GROUP.

The series of shales and limestones which make up the Cincinnati or Hudson group in Kentucky occupy most of the north-central portion of the State. The group consists of dark blue, argillaceous, thin-bedded limestones, with frequent interbedded shales. The limestones are usually of satisfactory composition for use as cement materials. The shales, however, are frequently sandy in the southern and western parts, but it is probable that even here shale beds of satisfactory composition could be found on careful search.

North of a line connecting Madison, Ind., and Maysville, Ky., the Cincinnati limestones are pure and the shales are calcareous and never arenaceous. In going southward from this line both the shales and the limestones, particularly in the middle part of the group, gradually grow more and more sandy. Along the Cumberland River (in southern Kentucky) practically the whole group is represented by a fine-grained sandstone. This has been called by Shaler the Cumberland sandstone.

U S GEOLOGICAL SURVEY

GEOLOGIC MAP OF KE

Revised from maps of the Kentucky

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LE

CARBONIFEROUS

Coal Measures

Mississippian limestone

NTUCKY AND TENNESSEE

ky and Tennessee geological surveys

cale

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1904

LEGEND

ORDOVICIAN

Cincinnati shales and limestones

Trenton and Stones River limestones

Analyses of limestones from Cincinnati group, Kentucky.[a]

[R. Peter, analyst.]

	1	2	3	4	5	6	7	8	9	10
Silica (SiO_2)	14.44	6.38	13.98	10.42	1.89	3.68	7.18	16.64	1.72	0.78
Alumina (Al_2O_3) Iron oxide (Fe_2O_3)	3.75	2.20	3.91	2.03	.54	1.19	2.34	2.48	3.58	1.04
Lime carbonate ($CaCO_3$)	75.44	87.98	77.36	85.20	96.51	92.65	88.90	78.68	92.92	96.24
Magnesium carbonate ($MgCO_3$)	4.78	1.72	2.31	1.24	1.05	1.54	1.47	1.57	.56	.94
Alkalies (K_2O, Na_2O)	.83	.34	.49	.79	.25	.43	.22	.35	.32	.87
Sulphur trioxide (SO_3)	.47	.37	2.43	.17	.18	1.27	.24	.27	.34	.18

1. Mason County.
2. Mason County.
3. Mason County.
4. Anderson County.
5. Bourbon County.
6. Franklin County.
7. Mercer County.
8. Nicholas County.
9. Owen County.
10. Woodford County.

Excepting 5 and 10, which are of unusually pure limestones for their respective localities, and 9, which is nearly normal for the northern part of the Cincinnati outcrop, all these analyses illustrate the increase in silica southward, referred to above. In the central counties north of the Maysville-Madison line the limestones contain very little silica and agree closely with those in southwestern Ohio.

MISSISSIPPIAN OR "LOWER CARBONIFEROUS" LIMESTONES.

The Lower Carboniferous limestones are commonly low in magnesia; and in most of the area covered by them in Kentucky they are also high in lime carbonate. As the Tennessee-Kentucky State line is approached, however, interbedded layers of chert become more and more common, until the lower part of the series becomes too siliceous to be of much promise as a source of Portland-cement materials.

The lower Mississippian sandstone, or Waverly sandstone, shown on the map, is limited to the east side of the Cincinnati axis and north of Jackson County, Ky. South of Jackson County and west of the Cincinnati axis the equivalent strata consist, in central Kentucky, principally of shale, in which may occur considerable beds of siliceous limestone; in west Kentucky and middle Tennessee principally of siliceous limestone, with more or less shale in the lower part (= Tullahoma), passing southward into the Fort Payne chert.

In the Mississippian group there are two horizons or beds, both oolitic, that are important as future sources of Portland-cement material. The first, occurring at the base of the St. Louis and equivalent to the Spergen Hill (Bedford) limestone of Indiana, forms a generally broad strip passing through Meade, Hardin, Larue, Barren, Warren, Todd, Christian, and Trigg counties. The second is the Ste. Genevieve limestone, which is limited to Christian, Caldwell, Crittenden,

[a] From Kentucky Geol. Survey, pt. 2, p. 123.

and Livingston counties, in western Kentucky. Between the first strip and the border of the western Kentucky coal field there is first a broad strip of St. Louis limestone, which is usually too siliceous and too magnesian for use in making Portland cement, and then, near or just outside of the coal field, the limestones, shales, and sandstones of the Chester group.

The Chester contains several beds of apparently promising limestone closely associated with beds of shale.

No good limestones occur in west-central Tennessee except in Montgomery and Robertson counties, where the lower oolite is present. However, the St. Louis limestone here, as also in Kentucky, contains many beds of only slightly siliceous and probably nonmagnesian limestone.

Of the analyses below, Nos. 1 and 7 are Spergen Hill oolites, Nos. 3, 5, and 6 St. Louis limestone, and 2, 4, and 8 Chester limestones, though the last is extraordinarily pure for a Chester limestone.

Analyses of Upper Mississippian limestones from Kentucky.[a]

[R. Peter, analyst.]

No.	Silica (SiO_2).	Alumina (Al_2O_3); iron oxide (Fe_2O_3).	Lime carbonate ($CaCO_3$).	Magnesium carbonate ($MgCO_3$).	Alkalies (K_2O, Na_2O).	Sulphur trioxide (SO_3).
1	1.06	0.51	98.05	0.36	0.44	0.26
2	2.76	.92	93.02	2.09	not det.	.60
3	3.06	1.39	95.15	.24	not det.	Trace.
4	7.48	2.56	85.68	2.50	.36	.84
5	9.56	.15	88.15	.38	not det.	....
6	4.46	1.49	92.05	.22	not det.	.20
7	.38	.46	98.58	.63	.18	.27
8	.49	.22	97.63	.65	not det.	.34

1. Glasgow Junction, Barren County.
2. Barren River, Butler County.
3. Iron Hills Furnace, Carter County.
4. Grayson County.
5. Old Town Creek, Greenup County.
6. Kenton Furnace, Greenup County.
7. Hardin County.
8. Litchfield, Grayson County.

PENNSYLVANIAN OR "COAL MEASURES" LIMESTONES.

A number of limestone beds occur interbedded with the shales and sandstones of the Coal Measures. These Coal Measures limestones are usually low in magnesia, but rarely carry more than 80 to 90 per cent of lime carbonate. Compared with the thick series of lower Carboniferous limestones, they are so thin that they would be of but little importance if it were not for their advantageous location near supplies of fuel.

[a] Analyses 1 to 7 from Kentucky Geol. Survey, Rept. A, pt. 2, pp. 119-120; analysis 8 from Twentieth Ann. Rept. U. S. Geol. Survey, pt. 6, p. 545.

Analyses of Coal Measure limestones from Kentucky.

No.	Silica (SiO_2).	Alumina (Al_2O_3); iron oxide (Fe_2O_3).	Lime carbonate ($CaCO_3$).	Magnesium carbonate ($MgCO_3$).	Alkalies (K_2O, Na_2O).	Sulphur trioxide (SO_3).
1	14.70	6.40	75.75	0.57	n. d.	0.78
2	5.96	3.76	88.41	.79	0.51	.04
3	3.28	1.76	88.38	3.68	.35	.17
4	4.26	4.33	82.88	4.20	.29	4.72
5	1.15	.65	97.15	.93	....	....

Analyses 1 to 4 (by R. Peter) from Kentucky Geol. Survey, Rept. A, pt. 2, p. 119; analysis 5 communicated by F. E. Hayward.

1. Mount Savage Furnace, Carter County.
2. Pea Ridge, Greenup County.
3. Henderson County.
4. Muhlenberg County.
5. Hayward, Carter County.

PORTLAND-CEMENT RESOURCES OF LOUISIANA.

The great chalk formations, which seem destined to be such important sources of Portland-cement material in the neighboring States of Texas, Arkansas, Mississippi, and Alabama, fail to occur in Louisiana except as small isolated outcrops. The State is therefore practically devoid of limestone and can hardly be considered as a possible future producer of Portland cement. The few limestone outcrops that appear within its limits are described as follows: [a]

Cretaceous limestones.—The beds of limestone seem to be almost entirely confined to the Cretaceous. Of the three outcrops which occur in the State, the Winnfield limestone is of very doubtful value as a building stone, but the Coochie Brake and Bayou Chicot deposits may be utilized for that purpose.

The Winnfield limestone is a highly crystallized blue and white banded stone. It is full of cracks and pockets and other flaws, which will render it useless as an ornamental or building stone. It can doubtless be used to advantage for making lime. The quantity of the stone in sight is large and it can be very economically quarried. Several kilns of lime have already been burned there.

The purity of the stone is shown by the following analysis by Dr. W. F. Hillebrand, [b] of the United States Geological Survey:

Analysis of limestone from Winnfield.

Silica (SiO_2)	0.65
Alumina (Al_2O_3)	Trace.
Iron oxide (Fe_2O_3)	Trace.
Lime (CaO)	55.01
Magnesia (MgO)	.60
Sulphur trioxide (SO_3)	.27
Carbon dioxide (CO_2)	43.43
Water	.13

[a] Report Geol. Survey Louisiana for 1899, pp. 130–131.

[b] Bull. U. S. Geol. Survey No. 60, p. 160.

The Coochie Brake stone is a light-yellow or bluish-yellow, coarse-grained, sandy limestone. It is of excellent quality for building purposes, but its value is somewhat impaired by the presence of small nodules of iron pyrites. These will restrict its use to situations where a good external appearance is not one of the qualities required of the stone. The pyrite, if the quantity proves to be large, may destroy its value altogether. The quantity of stone at this locality is large, and it is easily obtained.

The Bayou Chicot stone is the best for building that we have seen in the State. It is a fine-grained dark-gray limestone. Only two very small outcrops of it were seen, and from these no very satisfactory ideas of the extent of the deposit could be gained. In the two outcrops the dip is very great, and the cost of uncovering the stone would probably be large. Borings are needed to show the depth of the deposit. In the early history of the country lime was made at this place. The ruins of the old limekilns are to be seen near the larger outcrop.

Analysis of limestone from Rayborn's salt lick, Bienville Parish. [a]

Silica (SiO_2)	0.55
Alumina (Al_2O_3) Iron oxide (Fe_2O_3)	1.61
Lime (CaO)	54.09
Magnesia (MgO)	.06
Sulphur trioxide (SO_3)	.05
Carbon dioxide (CO_2)	44.12

Tertiary limestones.—The concretions of limestone in the Tertiary beds are often of large size and have been used locally for the foundations of houses. At Shreveport large calcareous concretions are crushed and used on the streets and in concrete work. Hopkins reports a place 5 miles from Natchitoches, called the Kilns, where large concretions have been burned for lime.

At Rocky Spring Church lime was burned from a little outcrop of Tertiary limestone for the masonry of Fort Jessup.

PORTLAND-CEMENT RESOURCES OF MAINE.

Numerous more or less extensive limestone beds are known to occur in various parts of Maine, but few of these will be worth considering as possible sources of Portland-cement materials. Most of the outcrops are located far from fuel supply and cement markets, and the transportation question is particularly serious in a State having so low a railroad mileage as Maine. Geologic mapping has not progressed sufficiently to give even a fairly accurate map of the limestones of the State, and few satisfactory analyses are available. It is practically certain, however, that the only limestones on which a Portland-cement industry can be based, under present conditions, are those which outcrop along or near the Altantic coast line.

As a source of Portland-cement material, it seems probable that some of the limestones which are now so extensively utilized for lime burning in the neighborhood of Rockland, Rockport, and Union, in Knox County, might prove available. These limestone deposits are of comparatively large size, and are located on or near deep water.

[a] Bull. U. S. Geol. Survey No. 188, p. 258; analysis by R. B. Riggs.

Glacial clays are abundant in the vicinity of the limestone, and it is probable that some of these clays can be found of suitable composition for a Portland-cement mixture. The Knox County limestones are of very satisfactory composition as cement materials, as is shown by the analyses quoted below.

Analyses of limestones from Knox County, Maine.

	1	2	3
Silica (SiO_2)	1.08	1.00	0.43
Alumina (Al_2O_3)	.07	....	.71
Iron oxide (Fe_2O_3)	.08	Trace.	.25
Lime carbonate ($CaCO_3$)	98.17	95.20	97.69
Magnesium carbonate ($MgCO_3$)	.09	1.00	.82
Water	n. d.	2.70	n. d.

1. McNamara quarry, Rockland. J. C. Robinson, analyst. Twentieth Ann. Rept. U. S. Geol. Survey, pt. 6, p. 398.
2. Bachelder quarry, Union. J. C. Robinson, analyst. Ibid.
3. Rockland-Rockport Lime Company. Communicated by G. O. Smith, 1904.

Limestone beds of considerable extent also occur near Islesboro. A specimen from this locality, collected by G. O. Smith, was analyzed by W. T. Schaller in the laboratory of the United States Geological Survey, and proved to be a very pure limestone, low in magnesia.

Analysis of limestone from Islesboro, Me.

Silica (SiO_2)	3.76
Alumina (Al_2O_3)	1.03
Iron oxide (Fe_2O_3)	.43
Lime (CaO)	51.30
Magnesia (MgO)	1.16

The following analysis, communicated by G. O. Smith, is of a clay occurring on the property of the Rockland-Rockport Lime Company, in Knox County. As can be seen from the analysis, it would serve well to mix with the limestones above noted:

Analysis of clay from Knox County, Me.

Silica (SiO_2)	61.59
Alumina (Al_2O_3)	19.10
Iron oxide (Fe_2O_3)	7.53
Lime (CaO)	1.68
Magnesia (MgO)	1.87
Carbon dioxide (CO_2) Water	5.51

The analyses of limestones given in the following table are quoted from an early report, by Professor Hitchcock, on the geology of Maine. They are inserted here, as they may serve to some extent as

a guide to the limestone prospector. It should be noted, however, that the quality of the analyses is not above suspicion, and also that many of the beds analyzed may prove to be entirely too small to work with profit:

Analyses of Maine limestones.

No.	County.	Locality.	Insoluble.	Fe_2O_3.	$CaCO_3$.
1	Androscoggin	Turner	25.0	0.4	74.6
2	Franklin	Carthage	8.8	1.4	89.8
3	....do	....do	23.4	.4	76.2
4	....do	Farmington	6.4	4.8	88.8
5	....do	Farmington Hill	14.4	1.2	84.4
6	....do	Industry	21.2	2.8	76.0
7	....do	Livermore Falls	34.0	3.2	62.8
8	....do	New Sharon	36.0	10.2	53.8
9	....do	....do	20.6	2.4	77.0
10	....do	....do	10.2	1.6	88.2
11	....do	Phillips	34.4	.8	64.8
12	....do	....do	26.8	5.6	67.6
13	....do	....do	34.6	.4	65.0
14	....do	Strong	8.4	1.0	90.5
15	....do	Temple	28.4	1.4	70.2
16	Kennebec	Clinton	17.2	.6	76.8
17	....do	Winslow	24.2	2.0	73.8
18	....do	....do	31.0	.6	68.4
19	....do	....do	16.2	2.0	81.8
20	....do	....do	20.6	1.6	77.8
21	....do	....do	20.2	1.0	78.8
22	Oxford	Dixfield	29.2	1.4	69.4
23	....do	....do	20.0	.4	79.6
24	....do	Rumford Falls	20.8	1.2	78.0
25	Penobscot	Dexter	8.6	1.4	90.0
26	....do	....do	9.6	1.2	89.2
27	....do	....do	20.0	1.8	78.2
28	....do	....do	14.4	1.6	84.0
29	Piscataquis	Abbot	24.8	1.2	74.0
30	....do	Dover	25.4	4.0	70.6
31	....do	Guilford	13.8	1.4	84.8
32	Somerset	Athens	25.2	4.4	70.4
33	....do	....do	2.8	....	72.6
34	....do	Harmony	36.4	2.2	61.4
35	....do	Norridgewock	10.6	1.2	88.2
36	....do	West Waterville	24.8	1.4	73.8
37	....do	....do	9.0	1.2	89.8

PORTLAND-CEMENT RESOURCES OF MARYLAND.

Up to the present time no Portland-cement plants have been built in Maryland, but three limestone formations in the State are so well located and so satisfactory in chemical composition as to give promise of being future sources of supply of Portland-cement materials. Several other limestones occur, but are either too high in magnesia or otherwise not well adapted to cement manufacture. The three available limestone formations above noted are, in descending order, as follows:

Name.	Geologic age.
Greenbrier limestone	Mississippian.
Lewiston or Helderberg limestone	Silurian.
Trenton limestone	Ordovician (Lower Silurian).

The areal distribution of these three limestones in Maryland and the adjoining States is shown on the geologic map, Pl. XV, opposite page 314.

TRENTON LIMESTONES AND ADJACENT CLAYS.

DISTRIBUTION AND CHARACTER.

The Cambro-Ordovician limestones, including the Trenton limestone, which is the special object of interest here, occur in three principal areas in Maryland, two of which are in Washington County and one in Frederick.

The westernmost area enters Maryland from Pennsylvania in central Washington County, and runs in a direction slightly west of south to Potomac River, which it reaches between Cherry Run and Williamsport. The eastern border of this limestone belt lies just west of Conococheague Creek, while Little Conococheague Creek lies in the limestone area. Fairview, Reiffs, Hicksville, and Clear Spring are located on the limestone.

The central limestone belt covers almost all of the eastern third of Washington County. It enters from Pennsylvania as a broad belt, being about 15 miles wide at the State line. It underlies the Hagerstown Valley, Antietam Creek running down the middle of the belt for its entire extent. Hagerstown and Sharpsburg are located near the middle of the belt; Blue Mountain, Edgemont, and Weverton lie on or near its eastern edge, while Williamsport, Salisbury, and Mangansville are on or near the western border of the limestone.

The third and easternmost area of these limestones lies in the east-central portion of Frederick County, along Monocacy River. Frederick, Adamstown, Frederick Junction, Woodsboro, and Walkersville are located on this area of limestone.

It must be borne in mind that these limestone belts, as above described and as shown on the map, Pl. XV, opposite page 314, include two very different types of limestone, one of which is excellent as a Portland-cement material, while the second is absolutely worthless for that purpose, because of the very high percentage of magnesia that it usually contains. This fact is discussed in considerable detail in the descriptions of the Lehigh district cement rocks of Pennsylvania and New Jersey, and the reader will do well to look over the discussion there given (pp. 284 et seq.)

As a guide to searching for and recognizing the Trenton limestone, which is the one suited for cement manufacture, it may be said that the Trenton is usually dark gray to almost black in color, often slaty in appearance; that it frequently contains fossil shells, but rarely includes the beds or masses of chert which are so common in the underlying light-gray or blue magnesian limestone.

As the Trenton limestone is, moreover, the higher of the two limestones, it will usually be found along the contact between the limestone belt and the slates or shales which border it, while the magnesian limestones commonly occur near the middle of the belt of limestone.

COMPOSITION.

The Trenton limestone is almost invariably low in magnesia, and is therefore suitable for use as a Portland-cement material. In places it carries a high percentage of clayey matter, as is instanced by its composition in the Lehigh district of Pennsylvania and New Jersey.

The analyses below are fairly representative of the composition of the Trenton limestones of Maryland. It is probable that careful search along the contacts between the limestone belts and the adjoining slates or shales would show the presence of clayey limestones similar to the Lehigh cement rock in composition.

Analyses of Trenton limestones from Maryland.

<table>
<tr><th>No.</th><th>Silica (SiO_2).</th><th>Alumina (Al_2O_3).</th><th>Iron oxide (Fe_2O_3).</th><th>Lime carbonate ($CaCO_3$).</th><th>Magnesium carbonate ($MgCO_3$).</th></tr>
<tr><td>1</td><td>4.73</td><td colspan="2">1.40</td><td>93.57</td><td>0.30</td></tr>
<tr><td>2</td><td>4.31</td><td colspan="2">.90</td><td>81.97</td><td>13.00</td></tr>
<tr><td>3</td><td>.22</td><td>0.29</td><td>0.25</td><td>97.32</td><td>2.03</td></tr>
<tr><td>4</td><td>.10</td><td>.16</td><td>Trace.</td><td>96.79</td><td>2.86</td></tr>
<tr><td>5</td><td>.20</td><td colspan="2">.10</td><td>97.00</td><td>2.50</td></tr>
<tr><td>6</td><td>.50</td><td colspan="2">.10</td><td>98.50</td><td>.80</td></tr>
<tr><td>7</td><td>6.00</td><td colspan="2">.20</td><td>90.70</td><td>3.00</td></tr>
<tr><td>8</td><td colspan="3">0.2</td><td>94.6</td><td>5.2</td></tr>
<tr><td>9</td><td colspan="3">7.2</td><td>86.0</td><td>6.8</td></tr>
<tr><td>10</td><td colspan="3">.6</td><td>98.3</td><td>1.1</td></tr>
<tr><td>11</td><td colspan="3">Trace.</td><td>99.5</td><td>.5</td></tr>
<tr><td>12</td><td colspan="3">.5</td><td>92.0</td><td>7.5</td></tr>
<tr><td>13</td><td colspan="3">1.7</td><td>92.3</td><td>6.0</td></tr>
<tr><td>14</td><td colspan="3">.3</td><td>94.5</td><td>5.2</td></tr>
<tr><td>15</td><td colspan="3">.9</td><td>90.4</td><td>.7</td></tr>
<tr><td>16</td><td colspan="3">1.2</td><td>97.5</td><td>1.3</td></tr>
<tr><td>17</td><td colspan="3">2.2</td><td>95.3</td><td>2.5</td></tr>
<tr><td>18</td><td colspan="3">1.5</td><td>96.0</td><td>2.5</td></tr>
<tr><td>19</td><td colspan="3">.0</td><td>99.9</td><td>.1</td></tr>
<tr><td>20</td><td colspan="3">1.2</td><td>98.5</td><td>.3</td></tr>
<tr><td>21</td><td colspan="3">1.3</td><td>96.2</td><td>2.5</td></tr>
<tr><td>22</td><td colspan="3">.2</td><td>99.3</td><td>.5</td></tr>
</table>

1, 2. Walkersville, Frederick County. H. J. Patterson, analyst. Twentieth Ann. Rept. U. S. Geol. Survey, pt. 6, p. 401.
3, 4. Frederick, Frederick County. J. O. Hargrove, analyst. Ibid.
5. Beaver Creek, Washington County. J. Higgins, analyst. Third Rept. Maryland Agric. Chemist, p. 135.
6. Williamsport, Washington County. J. Higgins, analyst. Ibid.
7. Pleasant Valley, Washington County. J. Higgins, analyst. Ibid.
8, 9. Frederick, Frederick County. J. Higgins, analyst. Fifth Rept. Maryland Agric. Chemist, p. 78.
10–12. Unionville, Frederick County. J. Higgins, analyst. Ibid., p. 80.
13–15. Woodsboro, Frederick County. J. Higgins, analyst. Ibid., p. 77.
16, 17. Dollyhide Creek, Liberty, Frederick County. J. Higgins, analyst. Ibid., p. 80.
18–22. Near Liberty, Frederick County. J. Higgins, analyst. Ibid., p. 81.

METAMORPHIC TRENTON LIMESTONES.

In eastern Maryland, particularly in Carroll, Baltimore, and Howard counties, a number of areas of highly crystalline limestones or "marbles" occur. It seems probable that many of these crystalline limestones are of the same age as the Cambro-Ordovician limestones farther west, having merely assumed a crystalline condition as the result of being subjected to pressure and heat.

In composition these crystalline marbles vary, just as do the unmetamorphosed Cambro-Ordovician limestones. The Cockeysville marble,

for example, is highly magnesian, while the stone from Texas and other localities is just as low in magnesia as the best of the Trenton limestones.

Analyses of metamorphic (Trenton?) limestones from Maryland.

	1	2
Silica (SiO_2)	0.60	13.60
Alumina (Al_2O_3)	Trace.	5.15
Iron oxide (Fe_2O_3)	Trace.	
Lime carbonate ($CaCO_3$)	98.53	77.82
Magnesium carbonate ($MgCO_3$)	.87	3.19

1. Texas, Baltimore County. J. Higgins, analyst. Third Rept. Maryland Agric. Chemist, p. 77.
2. Highlands, Howard County. H. J. Patterson, analyst. Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 5, p. 1059.

ADJACENT CLAYS AND SHALES.

In case a Portland-cement plant is projected to utilize the more clayey types of the Trenton limestone—material like the Lehigh cement rock, for example—a small amount of pure limestone will be needed for mixture with this clayey limestone in order to bring it up to the proper composition for a Portland-cement mixture. In this case the requisite pure limestone can readily be secured from the lower portion of the Trenton limestone itself, this lower portion being usually a rock carrying from 93 to 98 per cent of lime carbonate.

The following analyses are of surface clays from near Williamsport, Washington County, used by the Conococheague Brick Company.

Analyses of surface clays from Maryland.

[H. Ries, analyst.]

	1	2	3
Silica (SiO_2)	67.50	n. d.	61.30
Alumina (Al_2O_3)	17.20	n. d.	22.30
Iron oxide (Fe_2O_3)	6.70	n. d.	3.80
Lime (CaO)	.45	0.22	.70
Magnesia (MgO)	.33	n. d.	.86
Alkalies (K_2O, Na_2O)	1.76	n. d.	2.10
Combined water	5.90	n. d.	8.00
Moisture	.20	n. d.	....

1. Dark-red clay.
2. Light-red clay.
3. Light-gray clay.
H. Ries, analyst: Md. Geol. Survey, vol. 4, p. 473.

If, on the other hand, the purer beds of the Trenton limestone are intended to furnish the principal ingredient, a clay or shale will be required for mixture with it. Surface clays of fair quality occur throughout the area underlain by the Trenton limestones, and some of them will probably be found available for use. In addition, the shales and slates of the Hudson formation, which borders the limestone belts, will be serviceable. The composition of some of these Hudson shales in Pennsylvania and Virginia is given in tables on pages 288 and 322.

HELDERBERG LIMESTONE AND ADJACENT CLAYS.

DISTRIBUTION.

The Helderberg or Lewistown limestone outcrops in Maryland in a number of different belts. Most of these are in the west-central portion of Allegany County, while several occur in western Washington County. The Lewistown limestone occurs only in these two counties. Its distribution in Allegany County is described as follows, by Mr. C. C. O'Harra, in the report on the geology of that county published by the Maryland Geological Survey:

The easternmost and largest area, shaped like a much constricted letter W, lies to the east, west, and south of Tussey Mountain, and by its prominent double bifurcation makes up a large part of Warrior Mountain and Martin Mountain. On the State line east of Tussey Mountain the Helderberg belt is less than one-half mile wide, while the width of the corresponding outcrop on the western side is considerably greater. Southward, owing to the pitching of the Tussey Mountain anticline, these bands gradually approach each other until, at a point near Rush, the two coalesce. Within less than 1 mile southward the area again becomes bifurcated, but this time, owing to the synclinal nature of the fold, the projecting parts are separated by the Oriskany formation, which immediately follows the Helderberg. Of the two southern Helderberg projections, the one farthest east is the more extensive, and includes within it Flakes Knob, the highest point in the county east of the Allegany Front. This part of the area narrows southward, but caps Warrior Mountain to within almost a mile of where the mountain ceases to be a distinct topographic feature. The projection lying farther west is much narrower than the one to the east, but continues almost as far south and acts as a capping for Collier Mountain.

The next area of Helderberg lies farther west and flanks the outcrop of Salina around Evitts Mountain in much the same way that the first area does the Salina around Tussey Mountain. The bifurcation at the north caused by the Evitts Mountain anticline is quite like that produced by the Tussey Mountain anticline. The formation continues southward in one long, continually narrowing band to within 1½ miles of the Potomac, where the Helderberg ending in a sharp point passes beneath the Oriskany to appear again at the roadside by the canal where the Potomac has cut entirely through the overlying Oriskany and into the Helderberg for a distance of fully a hundred feet. The eastern part of this area forms much of the crest and western slope of Nicholas Mountain, while the contact line along the western side is clearly marked by a row of hills extending from the State line southward. This row of hills reaches almost as far south as does the Helderberg outcrop, but finally coalesces with Nicholas Mountain.

East of Wills Mountain a belt of Helderberg averaging less than one-half mile in

width comes into the county from the north, and, extending southward along the western slope of Shriver Ridge, passes through the western part of Cumberland and across the Potomac into West Virginia. The Potomac in its very perceptible eastward bend nearly 3 miles above Cumberland, and again in the more prominent eastward bend about 6 miles above Cumberland, has carved out two small portions of this belt from the West Virginia area. These patches are mostly concealed, but their contact with the Salina is fairly well shown. Northward the Helderberg-Salina contact is largely concealed, but the limestone quarries which occur in the lower part of the Helderberg along the western base of Shriver Ridge afford a convenient means of judging the approximate western outcrop of the Helderberg. Shriver Ridge marks the eastern limit, as the contract lies on its western slope a short distance below the top.

West of Wills Mountain there is a band of Helderberg corresponding in position to the eastern belt, but by reason of the perpendicular attitude of the strata this belt is considerably narrower than the one on the eastern side. Following closely the general direction of Wills Mountain, it crosses the Potomac River at Potomac station. Along the belt north of the National Road the Helderberg-Salina contact is usually not well shown, but the Helderberg-Oriskany contact is prominent, the latter being represented by the steep ridges to the north and south of Corriganville. South of the National Road neither contact is well shown, although slight topographic features usually indicate their positions with reasonable accuracy.

Another Helderberg area of considerable extent is exposed south of Rawlings. This forms the body of the steep isolated ridge known as Fort Hill, which extends southward along the Potomac for a distance of about 4 miles.

In addition to the above-mentioned areas, two very slight exposures may be seen along the West Virginia Central Railroad, on the north and south sides of Monster Rock, near Keyser, W. Va. They are of little importance, except in so far as they are of value in helping to work out the structure in that part of the county.

In addition to the areas above described as occurring in the western and central parts of Allegany County, four narrow belts of the Helderberg limestone outcrop in the western portion of Washington County, their location being shown on the map (Pl. XV, p. 314). The best exposures of these limestones in the county, so far as location is concerned, are those near Hancock, on Potomac River.

DESCRIPTION AND STRATIGRAPHIC POSITION.

The stratigraphy of the Lewistown limestone is thus described by Mr. O'Harra in the report previously cited:

Lithologically, the Helderberg is preeminently a limestone formation. Argillaceous materials occur as impurities in some of the beds, but these are not important, and sandstones are almost wholly lacking. Thin bands of chert, which are white or yellowish-white in color, occur sparingly throughout the upper part of the formation. Most of the limestone in the upper part is heavily bedded, and much of it is highly fossiliferous. The lower part of the Helderberg is a dark-blue thin-bedded limestone, which in breaking gives a decided ring. This corresponds to the Tentaculite limestone of New York, which in Maryland is over 400 feet thick. In the field the contact between the Salina and the Tentaculite limestone is very marked because of the different weathering qualities of the two rocks. The Salina rock weathers into soil very completely, while the Tentaculite limestone leaves innumerable small, thin, dark-blue slabs upon the surface.

The thickness of the formation is nearly 800 feet. The two partial sections given

below are believed to represent the full thickness as well as a duplication of some of the middle beds as indicated. The Potomac section extends from the bottom of the formation to and includes a few inches of the coralline ledge. The 36-foot massive Stromatopora bed of the Devils Backbone section is believed to come in immediately above this, the other beds of the section continuing upward in the order named to the top of the formation.

The Devils Backbone section, measured along the Huntingdon and Broadtop Railroad east of Wills Creek, is as follows:

Devils Backbone section.

	Feet.
Helderberg-Oriskany contact	
Concealed	42
Light-gray fossiliferous limestone, with numerous layers; a very light colored chert	22
Light-gray massive fossiliferous limestone; breaks into rectangular blocks	16
Shaly limestone	1½
Bluish-gray limestone, breaking into shaly fragments; weathering indicates much argillaceous material	18
Massive *Stromatopora* beds	36
Shaly limestone, somewhat nodular	10
Light-gray massive limestone, with upper part containing layers of light colored chert	45
Thin-bedded limestone; the weathered surface covered with small bryozoans:	16
Dark-blue massive limestone, very hard and difficult to break; upper part filled with *Pentamerus galeatus*	36
Fine, shaly fossiliferous limestone	16
Massive, dark-blue fossiliferous limestone	40
Slightly argillaceous, thin bedded, fossiliferous limestone	14
Gray, arenaceous fossiliferous limestone, with layers of cherty material	16
Concealed to bottom of formation.	
Total thickness of exposure at this place	328½

The measurements made at Potomac station are as follows:

Section at Potomac station, Md.

	Feet.
Upper beds concealed; very massive light gray limestone, with a few feet of nodular limestone near the top; coralline layer near the top	95
Mostly concealed, but sufficiently exposed to show that the beds are generally made up of thin grayish limestones; some massive beds are present	240
Generally thin-bedded, dark-blue limestone, but with some heavy beds; fossiliferous	148
Thinly bedded, dark-blue fossiliferous limestones, with occasional papery shales	92
Helderberg-Salina contact.	
Total thickness of exposed Helderberg	575

COMPOSITION.

No analyses of Helderberg limestones from Maryland localities have been published; but, to judge from its composition in Pennsylvania and Virginia, it will be everywhere found to contain thick beds of nonmagnesian limestone suitable for use as a Portland-cement material. A number of analyses of this limestone from Pennsylvania and Virginia localities will be found on pages 281 and 324.

GREENBRIER LIMESTONE AND ADJACENT SHALES.

DISTRIBUTION.

As shown on Pl. XV, the Greenbrier outcrops only in Allegany and Garrett counties. A single belt passes through the western part of Allegany, running about S. 30° W., and crossing the Potomac River at a point about midway between Westernport, Md., and Keyser, W. Va.

In Garrett County the Greenbrier is better shown, appearing in a number of belts or areas. As described in the report on Garrett County, published by the Maryland geological survey, the six belts occurring in Garrett County are distributed as follows:

The most easterly of these areas is situated parallel to and about one-half mile west of the crest of Savage and Backbone mountains. It enters the county from Pennsylvania one-half mile west of the northeast corner of the county, and extends in a southwesterly direction to the West Virginia line, 1 mile north of Potomac stone. This belt is about 45 miles long and from one-fourth to one-half mile wide. It occupies a valley between the Pottsville (Savage Mountain) and the Pocono (Little Savage Mountain) ridges. This valley is drained at the north by the headwaters of Laurel Run and Savage River, and farther south by Little Savage River, Swamp Run, and Pine Swamp Run. Along the northern end of Backbone Mountain the line of outcrop is for a large part of the way up on the mountain side, but farther south it occupies a series of valleys like those along Savage Mountain, but less pronounced.

The second Garrett County area extends along the eastern side of Meadow Mountain in the valleys of Red Run and Meadow Creek Run as far as the confluence of the latter with Deep Creek, near Thayerville. Thence it extends in the same southwesterly direction, in a similar series of valleys between Hoop Pole Ridge and the ridge of Pottsville rocks to the west of it, to the West Virginia line at a point about 7 miles southwest of Oakland. This series of valleys is drained by branches of Deep Creek and of Miller Run and by White Meadow Run and Rhine Creek. The limestone belt is about 37 miles long and from one-eighth to one-half mile in width.

The third belt extends from a point near Thayerville on the one last described down the valley of Deep Creek to the mouth of Marsh Run, thence up the valley of Marsh Run to McHenry, thence in a westerly direction for 1 mile, where it bifurcates. One prong extends down the valley of Hoyes Run for about 1 mile, and then disappears under overlying formations. The other prong extends in a northwesterly direction through a valley to Sang Run. From here it extends down the Youghiogheny River to points 1½ miles north and 2½ miles south of Sang Run, where it dips under the overlying formation.

The fourth area extends from a point on the one last described at McHenry in a north-northeasterly direction in the valley parallel to and about one-half mile west of Negro Mountain as far as across the Pennsylvania line. This belt is about 15 miles long and one-eighth of a mile wide.

The fifth belt extends from a point on the third one, about 1 mile east of Sang Run, in a northerly and northeasterly direction, crossing the Pennsylvania line at Oakton. It occupies a sinuous line of valleys parallel to and about one-half mile east of the crest of Winding Ridge. The belt is about 13 miles long and one-eighth of a mile wide.

The sixth area enters the county from West Virginia near Cranesville, and extends south along the valley occupied by Pine Swamp and Muddy Creek as far as Browning Mill, and thence up the valley lying west of Snaggy Mountain for about 4 miles. Here it extends across the line into West Virginia.

DESCRIPTION.

The Greenbrier formation, where best developed in Maryland, consists of three distinct members. The lowest is a series of limestones, usually siliceous near the base, and varying from 27 to 46 feet in thickness. The middle member consists largely of shales, thin sandstones, etc., and varies from 88 to 98 feet in thickness. The upper member consists almost entirely of very pure limestones, and is from 65 to 85 feet thick.

The section below, quoted from the Garrett County report of the Maryland Geological Survey, will serve to illustrate the characters of the various members of the Greenbrier formation.

Section of Greenbrier formation at Crabtree, Garrett County.

	Feet.
Upper member:	
Argillaceous limestone	4½
Massive sandy limestone	13
Red sandy limestone	2
Gray limestone	3
Red calcareous shale	3½
Red sandy limestone	8
Gray sandy limestone with red bands	21
Gray limestone	10
	65
Middle member:	
Red shale, with thin bands of gray sandstone	80
Pure white sandstone	8
	88
Lower member:	
Gray limestone	27

COMPOSITION.

The upper member of the Greenbrier formation consists very largely of thick beds of pure limestone. These limestones have been very extensively used for flux and for lime burning, and their range in composition is fairly well established.

The series of analyses given below is representative of these upper limestones. They are commonly very low in magnesium carbonate, though occasional beds will show a prohibitive percentage of that ingredient. In places they carry sufficient silica, alumina, and iron oxide to approximate to the composition of the Lehigh cement rock, but usually it will be necessary to add a considerable proportion of clay or shale in order to bring the mixture up to correct composition for Portland cement.

Analyses of Greenbrier limestone from Maryland.[a]

	1	2	3	4	5	6	7	8	9	10
Silica (SiO_2)	13.65	13.46	8.57	20.95	17.00	4.47	3.65	11.52	5.11	5.24
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	5.44	12.48	2.38	41.10	2.74	2.70	8.44	3.37	2.56	1.98
Lime carbonate ($CaCO_3$)	79.16	72.92	88.73	37.35	64.12	86.73	85.87	74.48	89.08	84.58
Magnesium carbonate ($MgCO_3$)	1.21	1.15	.86	.91	15.75	6.38	1.30	10.99	3.17	7.49

1. Gerringer and Inglehart's quarry, Garrett County.
2. Offutt's quarry, Garrett County.
3. Crabtree, Garrett County.
4. South of Negro Mountain, Garrett County.
5. Offutt's quarry, Garrett County.
6. Findley's quarry, Piney Run, Garrett County.
7-9. Mouth of Stony Run, Allegany County.
10. Barrelville, Allegany County.

ADJACENT SHALES.

The following analyses[b] of Carboniferous shales from near Corinth, Garrett County, will serve to illustrate their range of composition. It will be seen that they often carry high percentages of iron oxide and that the ratio $\frac{\text{silica}}{\text{alumina} + \text{iron oxide}}$ rarely rises much above 2.5 and often falls below 2.

Analyses of Carboniferous shales from near Corinth, Md.

	1	2	3	4	5	6	7	8
Silica (SiO_2)	56.42	69.51	62.98	51.53	53.49	56.36	61.70	56.32
Alumina (Al_2O_3)	20.94	22.27	18.54	22.60	22.83	24.18	22.24	23.00
Iron oxide (Fe_2O_3)	10.60	.80	5.70	6.80	6.90	6.40	5.60	5.80
Lime (CaO)	Trace.	Trace.	2.44	5.40	2.91	.50	Trace.	1.47
Magnesia (MgO)	1.32	Trace.	.97	1.87	1.84	.82	1.44	.79
Alkalis (K_2O, Na_2O)	......	Trace.	......	......	......	......	......	......
Water	7.30	7.45	8.85	11.77	9.44	7.50	6.50	11.08

1. Red clay (bottom).
2. Fire clay or flint.
3. Buff clay.
4. Bottom blue clay.
5. Top blue clay.
6. Cistern.
7. Railroad clay.
8. Black shale, coal mine.

[a] These analyses are taken from the report by the Maryland geological survey on "Garrett County," pp. 221-222. All the analyses were made by T. M. Price.

[b] Geology of Garrett County, Maryland Geol. Survey, p. 219.

PORTLAND-CEMENT RESOURCES OF MASSACHUSETTS.

In the western part of Massachusetts extensive quarries are operated for both marble and lime. The stone quarried in this area is a highly crystalline limestone, or marble, of Cambro-Ordovician age. At many points this stone is highly magnesian, but the quarries located in the northwestern portion of the State, in Berkshire County, seem to produce almost exclusively a low-magnesia rock. The analyses given below are fairly representative of this product.

Unfortunately for the prospects of a Portland-cement industry in the State no shales occur near these limestones, while the glacial clays usually contain too much sand and pebbles to be worth considering as cement materials. This fact, taken in connection with the cost of fuel in this district, renders it improbable that Massachusetts will become a successful cement producer.

Analyses of limestones from Massachusetts.

	1.	2.	3.	4.
Silica (SiO_2)	0.69	0.31	n. d.	0.63
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	.06	.23	n. d.	.55
Lime carbonate ($CaCO_3$)	93.86	98.80	99.03	99.60
Magnesium carbonate ($MgCO_3$)	5.34	.37	.27	.49

1. North Adams Marble Company, North Adams, Berkshire County. W. P. Mason, analyst. Twentieth Ann. Rept. U. S. Geol. Survey, pt. 6, p. 106.
2. Cheshire Manufacturing Company, Cheshire, Berkshire County. Davenport & Williams, analysts. Ibid., p. 410.
3. C. H. Hastings's quarry, West Stockbridge, Berkshire County. J. B. Britton, analyst. Ibid., p. 411.
4. Adams Marble Company, Renfrew, Berkshire County. E. E. Olcott, analyst. Ibid., p. 410.

PORTLAND-CEMENT RESOURCES OF MICHIGAN.

PORTLAND-CEMENT MATERIALS.

Michigan now ranks third as a Portland-cement producer, being led only by Pennsylvania and New Jersey, but closely followed by New York. This high standing as a producer is due to the product of a number of cement plants, most of them using a mixture of marl and clay, but a few utilizing pure limestone with clay or shale.

The description of the cement resources and cement industry of Michigan, given in the following pages, is somewhat abridged from a report by Prof. I. C. Russell on The Portland Cement Industry in Michigan, published in the Twenty-second Annual Report of the United States Geological Survey, part 3, pages 629–685. Reports on the cement materials of the State have also appeared in volume 8 of the Michigan Geological Survey.

LIMESTONES.

Of the various limestone formations that outcrop in different parts of Michigan three have been utilized in the manufacture of Portland cement, while another formation yields limestones which have not so far been utilized, though low in magnesia and otherwise satisfactory as cement materials. The four limestone groups above noted will be described separately.

DUNDEE LIMESTONE.

This formation occurs at the base of the Devonian system, and, although usually concealed beneath glacial drift and surficial deposits, comes to the surface, as is indicated on the map (Pl. VII), in a belt from about 2 to 9 miles wide, trending northeast and southwest across Wayne, Monroe, and Lenawee counties, in the southeastern corner of the State. The same formation occurs also at the extreme northern end of the southern peninsula and on Mackinac and neighboring islands, as well as in the adjacent portion of the northern peninsula. The purest layer of limestone in the Dundee thus far discovered is extensively quarried at Sibley and Bellevue, near Trenton, in Wayne County, and is used in the manufacture of sodium bicarbonate, soda ash, and caustic soda near Detroit. The finely powdered calcium carbonate, resulting as a by-product from the manufacture of caustic soda, is used by the Michigan Alkali Company for making Portland cement at Wyandotte. This same limestone, on account of its unusual purity, is also extensively used in the manufacture of beet sugar.

The Dundee formation contains several beds of limestone, most of which, however, carry too high a percentage of magnesia to permit their use in making Portland cement under the standard now required in the composition of the finished product. Thus far only one layer, the celebrated 9-foot bed, best exposed at the Sibley quarries, described below, has been found sufficiently pure to be utilized in the industries mentioned above. The composition of the rock quarried at Bellevue and used by the Michigan Alkali Company at Wyandotte, is as follows:

Analysis of a limestone of the Dundee formation at Bellevue.

[Analyst, O. Button.]

Silica (SiO_2)	0.60
Iron oxide (Fe_2O_3), Alumina (Al_2O_3)	3.04
Calcium carbonate ($CaCO_3$)	95.24
Magnesium carbonate ($MgCO_3$)	1.00
Total	99.88

Russell describes this limestone as follows:

The limestone of the Dundee formation is also quarried 2 miles northeast of Dundee, Monroe County, where four layers of limestone are exposed, the composition of which is shown below:

Analyses of Dundee limestone from the "Christiancy quarry," near Dundee.[a]

[Analyses 1, 3, 5, and 6 by G. A. Kirschmeier, and analyses 2 and 4 by K. J. Sundstrom.]

	Number of analysis and designation of bed.					
	1(A).	2(A).	3(B).	4(B).	5(C).	6(D).
Silica (SiO_2)	0.48	0.70	1.10	1.86	2.78	0.81
Lime carbonate ($CaCO_3$)	90.80	98.10	86.80	86.96	77.60	95.00
Magnesium carbonate ($MgCO_3$)	6.87	.63	11.60	10.08	17.41	3.86
Iron oxide (Fe_2O_3)	.16	......	.12	} .62	{ .56	.41
Alumina (Al_2O_3)	....	......	....			......
Sulphur (S)	....	.055	....	1.23	....	......
Organic matter	1.69	....	....	....	1.63	......
Difference	.00	.515	.38	.357	.02	.08
Total	100.00	100.00	100.00	100.00	100.00	100.00

Bed A is uppermost; a gray limestone 1 to 2 feet thick, fossiliferous.
Bed B is a compact brownish limestone, bituminous, 4 to 4½ feet thick, fossiliferous.
Bed C is a soft, dark-gray limestone, without seams, 7 to 8 feet thick.
Bed D is similar to bed C, 8 feet thick; bottom of quarry.

The rocks exposed in the quarry near Dundee are considered by Sherzer as the identical layers that are extensively quarried near Trenton. When sufficiently low in magnesia the beds are evidently favorable for use in making Portland cement, the only questionable features seeming to be the expense of quarrying and crushing. Certain of the layers at Dundee contain petroleum, the influence of which on the mixing of slurry is not known.

The following notes concerning the Sibley quarry at Trenton, Wayne County, have been kindly furnished by Mr. Frank Leverett.

The quarry occupies an area of 35 acres. The rocks dip westward at the rate of about 5 feet in 100. There is a low anticlinal arch trending approximately east and west, which passes through the midst of the excavation, from the crest of which the beds dip away at the rate of about 1 foot in 100. The strata are cut by two systems of joints, bearing about N. 20° E. and N. 60° E. The quarry is situated in an irregular hill which rises about 30 feet above the level of the adjacent portion of Detroit River. On the higher portions of the hill there is no covering of drift, but on the sides the solid rock is concealed beneath several feet of till. Where the glacial deposits have been removed, the surface of the rock beneath is intensely glaciated. There are two sets of glacial grooves, of which the earlier bears about S. 28° W. and the later approximately N. 30° W.

[a] W. H. Sherzer, Geological report on Monroe County, Michigan: Geol. Survey Michigan, Vol. VII, pt. 1, 1900, pp. 75-76, 177-178.

The strata exposed in the quarry are as follows, beginning at the surface:

Section at Sibley quarry, Wayne County, Mich.

	Feet.
1. Thin-bedded gray limestone, suitable for use as a flux	3.5
2. "Upper 6-foot bed," a gray limestone, containing 96 per cent $CaCO_3$; used in alkali works; a portion of the lower part of the bed, about 8 inches in thickness, is now rejected on account of its containing too much bituminous matter	6
3. Fossiliferous blue-gray limestone, containing 90 per cent $CaCO_3$; suitable for use in alkali works	3
4. "Second 6-foot bed," a blue-gray limestone, containing from 94 to 95 per cent $CaCO_3$; used as a building stone and in alkali works	6
5. "Five-foot bed," very similar to "Upper 6-foot bed"	5
6. "Cherty bed," a cherty limestone, not at present utilized	2
7. "Third 6-foot bed," a blue-gray limestone, with a little chert in its lower portion; used in alkali works and as a building stone	6
8. "Nine-foot bed," a fossiliferous gray limestone; used in the manufacture of beet sugar and suitable for making Portland cement	9
9. "The 6-foot Magnesian limestone," dove colored	6
10. "The 8-foot bed," a thick-bedded gray limestone; used as building stone.	8
11. "The 10-foot bed," a gray limestone, of which the upper 3 feet contains about 85 per cent, the next 3 feet 95 per cent, and the lower 4 feet about 80 per cent $CaCO_3$; the lower portion contains from 3 to 4 per cent SiO_2; the middle portion of the bed is very fossiliferous	10
12. Brownish limestone, containing 15 per cent SiO_2, .5 per cent MgO, and about 85 per cent $CaCO_3$; this rock is marked with white spots, thought to be aluminum silicate; used as building stone; opened to a depth of about	4
Total	63.5

Chemical analyses of certain of the beds described above are given below:

Analyses of limestone from Sibley quarries.

[Analyst, K. J. Sundstrom.]

Constituent.	5. South part of quarry.	5. North part of quarry.	6.	8. Upper part.	8. Central part.	8. Lower part.	9.	10.	11. Central part.
Calcium carbonate ($CaCO_3$)	95.50	99.26	93.28	97.33	99.00	95.62	80.04	89.05	95.00
Magnesium carbonate ($MgCO_3$)	2.36	.21	4.11	1.84	.22	3.15	15.96	8.08	4.00
Alumina (Al_2O_3)	.30	Trace.	.40	Trace.	Trace.	Trace.	2.70	Trace.	Trace.
Silica (SiO_2)	1.04	.50	1.90	.64	.54	.96	1.02	2.20	.56
Total	99.20	99.97	99.69	99.81	99.76	99.73	99.72	99.33	99.56

TRAVERSE GROUP.

Russell describes this formation as follows:

The rocks designated by this name consist principally of shale and limestone, occur in succession next above the Dundee formation, and belong to the Devonian system. They form a belt, about 2 miles wide, which crosses Wayne and Monroe

counties, * * * but are there concealed beneath surficial deposits, and also form a broad area which crosses the northern end of the Southern Peninsula from Alpena, on the border of Lake Huron, to Frankfort, on the shore of Lake Michigan. The limestone of the Traverse group comes to the surface at Alpena and is utilized by the Alpena Portland Cement Company. In the quarry where it is well exposed it is a light-colored compact rock, carrying corals and other fossils. Its composition is as follows:

Analyses of limestone from the quarries of the Alpena Portland Cement Company, Alpena.

[Analyst, F. H. Haldeman.]

Constituent.	1	2	3	4	5	6	7	8	9
Silica (SiO_2)	0.36	1.77	0.33	0.38	1.38	1.64	1.46	0.42	0.68
Calcium carbonate ($CaCO_3$)	95.91	89.10	98.37	98.03	96.35	96.50	96.92	98.04	98.03
Magnesium carbonate ($MgCO_3$)	3.63	8.67	.92	1.36	.94	1.26	1.46	.98	1.05
Iron oxide (Fe_2O_3) / Alumina (Al_2O_3)	.13	.35	.18	.19	1.21	.27	.54	.18	.26
Total	100.03	99.89	99.80	99.96	99.88	99.67	99.90	99.72	100.02

1. Quarry C: Shell to be removed on stripping; 1 to 2 feet thick.
2. Quarry C: Top stratum, 2 feet thick.
3. Quarry C: Second stratum, 2 feet thick.
4. Quarry C: Third stratum, 4 feet thick.
5. Quarry C: Fourth stratum, 2 feet thick.
6. Quarry F: First stratum, 2 feet thick.
7. Quarry F: Second stratum, 1 foot thick.
8. Quarry F: Third stratum, 2 feet thick.
9. Quarry F: Fourth stratum, floor of quarry.

All samples show traces of sulphates and phosphates.

The favorable results in the manufacture of Portland cement obtained from the use of the limestones just considered will no doubt stimulate further search for favorably situated outcrops of the same formations, in which the accompanying map, showing where they may be expected to occur, will be of assistance.

"MICHIGAN SERIES."

Russell describes the Michigan series as follows:

Another formation containing limestone, present in southern Michigan, is designated as the "Michigan series" on the map [Pl. VII], and belongs to the * * * Mississippian * * *. The limestones occur principally in the upper portion of the system and outcrop on the borders of the coal-bearing rocks which form the surface. They are in great part concealed by glacial drift and other surficial rocks over an extensive area in the central part of the southern peninsula.

The limestone of the Michigan series outcrops at Bayport and Sebewaing, in Huron County, on the east side of Saginaw Bay; on the Charity Islands; at Bellevue, in the southwestern part of Eaton County; and near the Portage River, about 5 or 6 miles north of Jackson. Other localities where it is accessible no doubt occur. It has been quarried at Bayport, Bellevue, and near Jackson, and calcined to make lime. Its composition, as indicated by the following analyses (stated as published), is such as to make it suitable for use in the manufacture of Portland cement, but up to the present time it has not been utilized for this purpose.

Analysis of limestone from Bayport.

[Analyst, J. W. Langley.]

Silica	3.330
Oxide of iron and alumina	1.334
Carbonate of magnesia	.944
Carbonate of lime	91.538
Phosphorus and sulphur	Trace.
Organic matter and loss	2.854
	100.000

(Quicklime, 51.29.)

Analysis of limestone from Bellevue.

[Analyst, Carl Rominger.]

Carbonate of lime	96.00
Carbonate of magnesia	1.00
Hydrate of iron oxide	.50
Insoluble residue	1.50
	99.00

Analysis of limestone from Portage River.

[Analyst, Carl Rominger.]

Carbonate of lime	96.90
Carbonate of magnesia	1.00
Alumina and iron	.70
Insoluble residue	1.40
	99.00

The limestone of the "Michigan series" contains layers that are high in magnesia or are otherwise unfavorable for cement making, but in spite of this the formation is evidently worthy of careful attention from persons interested in the industry under review wherever it occurs near deposits of clay or shale and is suitably situated in reference to transportation facilities, etc.

All of the limestones referred to above are of marine origin and usually contain fossils, among which coral is frequently conspicuous. The rocks are usually compact and hard, and if employed in the manufacture of Portland cement must be crushed and ground to a fine powder. Except for the expense thus involved they are in certain instances as favorable for the use indicated as the marls described below.

MARL DEPOSITS.

Russell describes the marl deposits as follows:

Some idea of the abundance and wide distribution of marl deposits in the southern peninsula may be obtained from the map [Pl. VIII], on which those it has been convenient to locate are indicated. This is by no means a complete index of the total number of marl deposits that occur in the area represented, as it has not been found practicable to make a detailed survey for the purpose of mapping them. It is safe to say that those shown on the map are probably less than one-fourth of the total number that exists in the southern peninsula. Those indicated on the map, with possibly a few exceptions, have an area in excess of 50 acres, and an average depth of 10 feet or more.[a] The marl beds of Michigan only are considered in this

[a] In the compilation of the data shown on the map, I have been assisted by Dr. A. C. Lane, State geologist, Prof. C. A. Davis, of Alma College, and others. [Note by Russell.]

report, but deposits of the same character are known to occur in neighboring States, as well as in the adjacent portions of Canada, but their entire distribution and their precise relation to climatic and geological conditions, etc., have not been determined. In extent the marl beds vary from a few acres up to several hundred acres. Some of the Portland-cement companies, it is stated, have marl beds from 500 to 1,000 acres in area, with an average depth of 20 feet or more. Im most instances these figures probably refer to two or more separate but perhaps closely adjacent beds. It is safe to say, however, that single beds from 100 to 300 acres in area and with an average depth of 20 feet or more are not rare.

In depth the marl beds vary from a few inches up to over 35 feet, as has been demonstated by the writer by actual borings. Other observers report depths up to 50 and even in excess of 70 feet, which are no doubt reliable measures.

The marl beds occur principally in the basins of existing lakes, but frequently extend beyond the present water margins and underlie the bordering swamp. They are present also in many instances beneath beds of peat or muck, from a few inches to several feet thick, on which tamarack and other trees grow. The presence of marl beds about the borders of existing lakes and at an elevation in some cases of 10 or 15 feet above their surfaces shows that the lakes have been lowered, usually by the cutting down of their outlets, since the marl began to form. In some examples peat occurs beneath extensive marl beds, and in a few cases two or three alternations of layers of peat and marl have been discovered. Usually, however, there is but one bed of marl present, which rests on a sandy or clayey bottom. It is evident in all instances that the marl was deposited in a lake, and that the swamps, or in some instances the now well-drained tracts where it is found, were formerly flooded.

Analyses of Michigan marl.

Locality.	Analyst.	Silica (SiO_2)	Alumina (Al_2O_3)	Iron oxide (Fe_2O_3).	Lime (CaO).	Lime carbonate ($CaCO_3$).	Magnesia (MgO)	Magnesium carbonate ($MgCO_3$)	Sulphur trioxide (SiO_3).	Loss on ignition.	Organic matter.	Remarks.
Alpena	E. D Campbell	8.13	3.06		43.09	a 76.76	0.54	a 1.13	....	44.99	....	From lake about 7 miles north of Alpena.
Bronson	W. H. Simmons	1.75	1.67		a 49.24	87.92	a .44	.92	0.15	....	7.50	Used by the Bronson Portland Cement Company.
Coldwater	E. D Campbell	.52	.51	.53	51.66	a 92.25	1.37	a 2.87	.89	....	....	Used by the Michigan Portland Cement Company.
Do	H E. Brown	15	.27	.19	46.20	a 82.51	.88	a 1.85	....	....	.05	$CO_2=36.30$ These two analyses show the extreme range in composition of the Portland Coldwater.
Do	do	8.60	1.30	1.54	54.69	a 97.52	2.78	a 5.84	....	....	10.50	$CO_2=42.90$ water.
Crapo Lake	Lathbury and Spackman.	1.46	.36		50.75	a 90.62	1.46	a 3.07	....	45.02	....	Furnished by the Hecla Portland Cement and Coal Company.
Fenton	E. D. Campbell	.48	.17	.51	52.28	a 93.25	1.85	a 3.88	.56	44.47	....	From Mud Lake, Shiawassee County.
Do	do	1.36	.56	.36	50.08	a 89.34	1.95	a 4.10	.69	45.72	....	Furnished by Detroit Portland Cement Company
Do	do	.55	.14	.54	51.76	a 92.15	1.90	a 3.99	....	45.32	....	
Do	do	.90	.20	.39	51.57	a 92.09	1.68	a 3.52	.46	45.86	....	From Silver Lake, Shiawassee County. Furnished by Detroit Portland Cement Company.
Fourmile Lake	do	6.66	3.17	1.36	a 47.09	84.09	a 1.77	3.72	1.25	....	....	Near Chelsea, Washtenaw County.
Grayling Lake	R. C. Kedzie	1.90	.14	.10	45.16	a 79.86	.32	a .67	.56	....	5.69	Also: $K_2O=0.37$; $Na_2O=2.65$; $CO_2=43.10$; $P_2O_5=.01$ Mich. Agr. Expt. Sta. Bull. No. 99, 1893.
Jackson	E. D. Campbell	2.73	1.21	.46	50.56	a 90.32	1.61	a 3.39	.39	....	....	From near Jackson
Lime Lake	Dearborn Drug and Chemical Works, Chicago.	1.30	.70		a 53.19	94.98	1.44	a 3.02	Trace.	....	....	Near Lakeland, Livingston County. From Prospectus of the Standard Portland Cement Company.
Ludington	E. D. Campbell	1.85	.65	.40	51.83	a 92.50	1.08	a 2.16	.22	....	....	
Lupton	Lathbury and Spackman	.24	.08		52.97	a 94.56	1.13	a 2.37	.08	45.49	....	In Ogemaw County. From Prospectus of the Lupton Portland Cement Company.
Do	do	.25	.19		52.28	a 93.53	1.14	a 2.39	.18	46.05	....	Do.
Mills Lake	do	.70	.46		50.43	a 90.07	1.26	a 2.65	....	47.08	....	In Ogemaw County. Furnished by Hecla Portland Cement and Coal Company.

Mosherville	(Not given)	.91	29		a 52.15	93.12	a 1.42	2.98	.31	....	2	
Do	E. D. Campbell	.20	.50	.60	50.12	a 89.50	.83	a 1.74	58	45.86	.....	
Pleasant Lake	Lathbury and Spackman.	.84	.28		51.28	a 91.57	1.77	....	....	45.60	.....	
Plummer Lake	do	1.78	.61		52.38	a 93.53	1.49	a 3.13	....	44.31	.....	
Runyan Lake	E. D. Campbell	.28	.65	.67	52.66	a 94	1.75	a 3.67	.38	42.44	.....	
Union City	A. Lundteigen	1.95	1.10		52.25	a 93.32	....	....	....	42.40	.....	
Do	do	.50	.66		44.95	a 80.32	....	....	....	36.30	.....	
Wetzell	E. D. Campbell	1.44	.28	.16	51.98	a 92.75	1.15	a 2.41	.084	44.25	.....	
Do	do	.82	.49	.36	52.94	a 94.53	.92	a 1.93	.15	44.50	.....	
White Pigeon	H. A. Huston	.37	.56		51	a 91.09	1.02	a 2.14	....	....	4	
Woodstock	J. G. Dean	.38	.68		50.76	a 90.66	.86	a 1.81	Trace.	46.62	.....	
Zukey Lake	E. D. Campbell	.96	....	.62	a 52.60	a 93.92	1.79	a 2.76	.58	....	....	Furnished by the Standard Portland Cement Company.
Do	Dearborn Drug and Chemical Works, Chicago.	1.30	.58		52.98	a 94.52	1.44	a 3.02	Trace.	....	....	Do.

a Computed from the analyses as reported

SHALES AND CLAYS.

Surface clays as well as shales from the Traverse and Coldwater formations have been used in Portland-cement plants in Michigan. In addition, shales from the Antrim and Saginaw formations may furnish supplies in the future.

The following descriptions of shales and clays are taken from Russell's report:

The shale of the Traverse group is utilized by the Alpena Portland Cement Company in connection with limestone from the same formation, and is obtained from quarries about 7 miles north of Alpena and near the shore of Lake Huron. The strata are nearly horizontal and consist of alternating layers of fine-grained and uniform bluish-black shale alternating with thin-bedded impure limestone. At the locality where the quarries are located the shale occurs at the surface, being covered only by 2 or 3 feet of peat. The same bed is understood to occur in the low bluff bordering the neighboring portion of Lake Huron. The surface portion of the shale where now exposed is disintegrated to a depth of a few inches, so as to form a stiff blue clay, and both the surface material and the unweathered shale beneath are suitable for cement making. The general composition of the shale is indicated by the following analyses:

Analyses of shale of the Traverse group from near Alpena.[a]

[Analysts, A. N. Clark (A) and H. Ries (B).]

Constituent.	A.	B.
Silica (SiO_2)	55.95	58.60
Alumina (Al_2O_3)	17.43	17.66
Ferric oxide (Fe_2O_3; all iron computed as Fe_2O_3)	7.67	7.44
Calcium carbonate ($CaCO_3$)	2.14	2.14
Magnesium carbonate ($MgCO_3$)	1.55	2.14
Alkalies, as K_2O	2.86	....
Water, organic matter and difference	12.40	11.97
Total	100.00	100.00
Ferrous iron (FeO)	.50	....

Another analysis of shale from the same locality as the above, supplied by the Alpena Portland Cement Company, is as follows:

Analysis of shale of the Traverse group from near Alpena.

[Analyst, S. H. Ludlow.]

Silica (SiO_2)	57.96
Alumina (Al_2O_3)	20.44
Ferric oxide (Fe_2O_3)	3.03
Calcium carbonate ($CaCO_3$)	9.12
Calcium oxide (CaO)	.28
Magnesium carbonate ($MgCO_3$)	5.02
Sulphuric anhydride (SO_3)	.72
Alkalies (Na_2O and K_2O)	3.40
Total	99.97

[a] Geol. Survey Michigan, vol. 8, pt. 1, p. 16.

The region in the northern portion of the southern peninsula in which shales of the Traverse group may outcrop on the borders of lakes or along streams, or may be discovered by making small excavations, is indicated on the map.

COLDWATER SHALES.

The Coldwater shales are now being quarried at a locality about 1½ miles east of Union City and utilized by the Peerless Portland Cement Company. At the quarry referred to the shales are well exposed to a depth of from 20 to 35 feet, are thin bedded, horizontal, and contain irregular concretions of ferrous carbonate, some of which are charged with fossil marine shells. The rocks near the surface are much weathered and so completely disintegrated that the evenly bedded bluish shales below pass upward into yellowish mottled clays near the surface. In the manufacture of Portland cement an approximately equal mixture of the weathered and unweathered material is now used. The range in percentage of the several constituents composing the shale is as follows:

Analyses of Coldwater shale from near Union City.

[Analyst, A. Lundteigen.]

Silica (SiO_2)	67.89 to 59.20
Iron and aluminum oxides (Fe_2O_3 and Al_2O_3)	29.89 to 23.33
Calcium (CaO)	1.42 to .00
Magnesium (MgO)	2.16 to .26
Sulphuric anhydride (SO_3)	Trace to .00
Alkalies, by difference	8.55 to 6.00
Moisture, including water of composition	20.50 to 10.00

The Coldwater shales are also used at the works of the Michigan Portland Cement Company, near Coldwater, and there present about the same characteristics as at Union City. Their range in composition is as follows:

Analyses of Coldwater shale from near Coldwater.

[Analyst, H. E. Brown.]

Silica (SiO_2)	57.26 to 61.25
Alumina (Al_2O_3)	18.12 to 21.59
Ferric oxide (Fe_2O_3)	6.53 to 8.30
Calcium (CaO)	1.25 to 1.50
Magnesium (MgO)	1.49 to 2.31
Sulphuric anhydride (SO_3)	.65 to 1.34
Carbon dioxide (CO_2)	.95 to 1.18
Titanium oxide (TiO_2)	.82 to 1.12
Alkalies (Na_2O and K_2O)	2.25 to 3.45
Loss on ignition	6.19 to 8.32

The shales of this formation were formerly used by the Bronson Portland Cement Company, but have been superseded by surface clays obtained in northern Ohio. The shale formerly used at Bronson is reported to have the following composition:

Analysis of Coldwater shale from near Bronson.[a]

[Analyst, C. J. Wheeler.]

Silica (SiO_2)	62.00
Alumina (Al_2O_3)	20.00
Ferric oxide (Fe_2O_3)	8.00
Calcium (CaO)	.50
Manesium (MgO)	1.00
Sulphuric anhydride (SO_3)	.50
Organic matter	8.00
Total	100.00

[a] The plant of the Bronson Portland Cement Company, Bronson, Mich., by H. Lewis: Eng. Rec., vol. 37, 1898, pp. 470-472; reprinted in The Cement Industry, New York, 1900, pp. 33-44.

Other analyses of the shales of this formation occurring near Bronson, Coldwater, and at White Rock, compiled from Ries's report, are as follows:

Analyses of Coldwater shale.

[Analyst, H. Ries.]

Constituent.	Bronson.	Coldwater.	White Rock.
Silica (SiO_2)	62.10	53.44	58.70
Alumina (Al_2O_3)	20.09	24.80	18.31
Ferric oxide (Fe_2O_3)	7.81		
Calcium (CaO)	.65	.76	....
Calcium carbonate ($CaCO_3$)	....	....	1.80
Magnesium (MgO)	.96	.25	....
Magnesium carbonate ($MgCO_3$)	....	....	.98
Sulphuric anhydride (SO_3)	.49	....	....
Alkalies (Na_2O and K_2O)	....	....	3.67
Water and organic matter	7.90	20.75	9.35
Total	100.00	100.00	100.00

The Coldwater shales occur beneath the surficial deposits throughout an extensive area in the southern peninsula, * * * but are seldom well exposed at the surface. As noted by Ries,[a] however, extensive outcrops occur along the shore of Lake Huron between White Rock and Forsyth, and are favorably situated for shipping by water.

At many localities where suitable surface clays can not be had in connection with extensive marl deposits it may be found practicable to mine the underlying Coldwater shales, as was formerly done near Bronson, for use in cement making.

ANTRIM SHALES.

In addition to the deposits briefly described above, there are two formations in the southern peninsula which contain shales that, in certain instances, at least, are worth investigating in connection with the industry here considered. These are the Antrim shales, which occur at the summit of the Devonian system, and the Saginaw formation, which forms the upper portion of the Carboniferous system as developed in Michigan.

The Antrim shales usually contain a high percentage of organic matter and yield petroleum, gas, etc., on distillation. No attempts have yet been made to utilize them for making cement, although their physical properties (except, perhaps, their toughness, which renders them somewhat difficult to quarry or to reduce to a powder) and their chemical composition make them worthy of experiment in that connection. An analysis of probably unweathered Antrim shale, made for the purpose of testing its fuel value, published by Ries,[b] is as follows:

Analysis of Antrim shale.

[Analyst, W. H. Johnson.]

Volatile matter	17.96
Fixed carbon	6.49
Ash	75.55
Total	100.00

[a] Geol. Survey Michigan, vol. 8, Pt. I, 1900, p. 44. [b] Ibid p. 47.

Analysis of the ash.

Silica (SiO_2)	70.54
Alumina (Al_2O_3)	15.33
Ferric oxide (Fe_2O_3)	5.31
Calcium (CaO)	2.38
Magnesium (MgO)	.78
Alkalies, etc., by difference	5.56
Total	100.00

As remarked by Ries, the ratio of silica to alumina in this analysis is unusually high, but so far as can be judged this material is worth careful investigation on the part of cement makers.

The Antrim shales are exposed on the shore of Thunder Bay, and also at several localities in Charlevoix County, where they are associated with marl deposits. The availability of these shales in manufacturing Portland cement and the utilization of the organic matter they contain as a by-product seems to be a possibility worthy of consideration.

SAGINAW FORMATION.

The shales of the coal-bearing rocks which underlie an extensive area in the central portion of the southern peninsula, and are well developed in the productive coal field of the Saginaw Valley, although frequently containing sand, have in some instances approximately the physical and chemical composition desired in cement making. The fact that these shales are frequently removed in the process of coal mining and that facilities for transportation are available claim for them careful attention as a source of material for use in manufacturing Portland cement.

As stated by Ries,[a] three types of shale in the Saginaw formation may be recognized, between which there are intermediate gradations. These are—

First. A light-gray, sandy, shaly clay, often quite hard, called "fire clay," and not infrequently containing fossil plants. Shale of this character is present beneath a coal seam at the mines of the Standard Mining Company, near Saginaw, and has the following composition:

Analysis of shale from Saginaw.

[Analyst, H. Ries.]

Silica (SiO_2)	55.30
Alumina (Al_2O_3)	14.20
Ferric oxide (Fe_2O_3)	3.62
Calcium carbonate ($CaCO_3$)	.30
Magnesium carbonate ($MgCO_3$)	2.61
Alkalies (K_2O, Na_2O)	2.15
Water and organic matter	21.82
Total	100.00
Fluxes	8.68

This shale is evidently too low in alumina and iron in proportion to the silica present to be used to advantage in the manufacture of Portland cement as now practiced.

Second. A black, fine-grained, brittle shale, with dull luster, sometimes termed "cannel coal." It contains much bituminous matter and would not serve well for the manufacture of clay products (Ries).

[a] Geol. Survey Michigan, vol. 8, pt. 1, 1900, pp. 25-38.

Third. A dark, grayish-black, fine-grained, hard, yet brittle, shale, which is appreciably plastic when ground and mixed with water. Shale of this type is found in several of the mines near Saginaw and Bay City, and is quarried at Flushing for the manufacture of paving brick. Similar shales are associated with coal seams near Jackson and may be expected to occur throughout the area indicated as being occupied by the Saginaw formation.

The chemical composition of the shales just referred to is indicated by the following analyses:

Analyses of shales of the Saginaw formation.

Constituent.	1	2	3	4	5	6
Silica (SiO_2)	54.50	52.45	57.10	61.13	54.93	41.38
Alumina (Al_2O_3)	30.75	23.27	20.02	26.90	31.43	27.02
Ferric oxide (Fe_2O_3)	3.50	7.93	8.18			
Calcium (CaO)	1.05	....	....	1.12	.22	.52
Calcium carbonate ($CaCO_3$)	....	1.82	.71	....	....	....
Magnesium (MgO)	1.69	....	....	.96	1.58	.90
Magnesium carbonate ($MgCO_3$)	....	1.06	1.47	....	....	....
Sodium oxide (Na_2O)	.80	4.37	2.76	(?)	(?)	(?)
Potassium oxide (K_2O)	2.20			(?)	(?)	(?)
Water and organic matter	5.51	9.10	9.76	6.47	7.44	23.11
Total	100.00	100.00	100.00	96.58	95.60	92.93
FeO	....	1.57	1.47	....	....	....

1. Fine-grained, black shale from Flushing. Analyst, H. Ries. Geological Survey of Michigan, vol. 3, pt. 1, 1900, p. 30.
2 and 3. Shales associated with coal at Bay City. Analyst, A. N. Clark. Ibid., pp. 35-36.
4, 5, and 6. Coal mines at Bay City. Analyses furnished by the Hecla Portland Cement and Coal Company. Analysts, Lathbury and Spackman.

As shown by these analyses, the shales of the Saginaw formation as a rule are lower in silica than is deemed desirable for use in making Portland cement, but certain beds have been recommended by experts in that industry. Evidently any layer of shale in the Saginaw formation which can be economically mined, and which is free from sand and other objectionable substances visible to the eye, should be carefully tested and experimented with in connection with the industry under review.

CLAYS.

Surface clays deposited during the Pleistocene period of geological history—that is, at a late date, and after the land had about its present relief—are abundant throughout Michigan. These clays were in part left on the surface of the country directly by the glaciers during the last ice invasion of the Glacial epoch, or in some instances by streams flowing from the glaciers; in part were laid down in small lakes and in the waters of the Great Lakes when more widely expanded in certain directions than at present, and in part were spread out in the flood plains of streams. These three varieties may be termed, to adopt the classification used by Ries,[a] drift clays, lake clays, and river silts.

The drift clays are invariably calcareous and usually contain sand, stones, and bowlders, and show much variation in composition. They are the most abundant of

[a] Geol. Survey Michigan, vol. 8, pt. 1, 1900, pp. 48-62.

the surface clays and frequently form the hills and upland. In numerous instances they are used in the manufacture of bricks, titles, etc., although in general not well adapted for this purpose. On account of their usual sandy and stony character and irregularities in composition, they are seldom worth investigating in reference to the making of Portland cement. In some exceptional instances, however, the glacial clays are essentially free from gravel and sand, but contain at intervals irregular nodules of calcium carbonate, which, if the material were used in making cement, would necessitate great care in mixing and grinding to form a slurry.

The chemical composition of typical examples of drift clay, when free from gravel and sand, is here presented:

Analyses of drift clays.

Constituent.	1	2	3	4	5	6
Silica (SiO_2)	54.94	45.27	46.22	40.15	41.86	52.26
Alumina (Al_2O_3)	12.14	15.33	15.02	11.25	10.70	22.95
Ferric oxide (Fe_2O_3)	4.88	6.65	5.49	4.88	5.02	8.15
Lime (CaO)	9.13	11.32	10.85	....	14.33	4.48
Calcium carbonate ($CaCO_3$)	....	....	....	21.43	....	....
Magnesia (MgO)	3.65	4.08	4.52	....	2.81	1.32
Magnesium carbonate ($MgCO_3$)	....	....	....	8.93	....	....
Sulphuric anhydride (SO_3)	None.	Trace.	Trace.	....	....	....
Carbon dioxide (CO_2)	....	....	....	....	14.56	....
Sodium oxide (Na_2O)	(?)	....	....	2.06	2.80	....
Potassium oxide (K_2O)	(?)	....	....			....
Water and organic matter [a]	12.44	13.75	15.31	11.30	8.00	10.56
Sand	....	3.44	1.20	....	....	....
Total	97.16	98.84	98.61	....	100.08	99.72

[a] Loss on ignition.

1. Brickyard near Pinckney, Livingston County. Furnished by Standard Portland Cement Company. Analysis by E. D. Campbell.
2. From 3 miles north of Jackson. Furnished by Standard Portland Cement Company. Analysis by E. D. Campbell.
3. From near Stockbridge, Ingham County. Analysis by E. D. Campbell.
4. From Ionia, Ionia County. Analysis by A. N. Clark. Geol. Survey Michigan, vol. 8, pt. 1, 1900, pp. 51-53.
5. From near Jackson, Jackson County. Analysis by H. Ries. Geol. Survey Michigan, vol. 8, pt. 1, 1900, pp. 56-59.
6. From Springport Township, Jackson County. Analysis by Mariner and Hoskins. Geol. Survey Michigan, vol. 8, pt. 1, 1900, p. 60.

The lake clays are well represented, especially about the border of the southern peninsula, as between Detroit and Ypsilanti, about Port Huron, South Haven, widely over the Saginaw Valley, and in numerous local basins throughout the State. In the Upper Peninsula extensive deposits of exceedingly fine-grained, laminated pinkish clay, deposited from the water of Lake Superior when more widely expanded than now, occur in abundance at Sault Ste. Marie, and have a wide distribution westward, as at Marquette, Escanaba, etc. The chemical composition of this extensive deposit is indicated by analysis 6 in the following table, which shows that it is suitable for cement making.

The lake clays here referred to are characteristically fine grained, many times almost entirely free from grit, highly plastic, and uniform in composition. As shown by numerous chemical analyses, however, they are what are termed "lean clays;"

that is, not high in alumina and ferric oxide in proportion to the silica present, and not, as a rule, considered favorable for cement making. These properties and the usual presence of lime, together with the frequent occurrence of sulphuric anhydride, are shown by the following analyses:

Analyses of lacustral clays.

Constituent.	1	2	3	4	5	6
Sand	....	....	1.51	....	(?)	....
Silica (SiO_2)	49.75	49.34	66.49	47.75	46.40	61.62
Alumina (Al_2O_3)	13.06	14.50	9.87	17.60	16.4 (Alumina and ferric oxide together)	17.20
Ferric oxide (Fe_2O_3)	5.31	5.37	4.87	9.13		5.99
Lime (CaO)	10.86	9.75	4.72	....	....	5.62
Calcium carbonate ($CaCO_3$)	....	....	....	2.60	25.36	....
Magnesia (MgO)	4.28	4.77	1.22	....	....	2.82
Magnesium carbonate ($MgCO_3$)	....	....	....	.70	4.30	....
Sulphuric anhydride (SO_3)	....	.13	.62	....	....	.46
Sodium oxide (Na_2O)	(?)	(?)	(?)	2.21 (Sodium and potassium oxides together)	....	....
Potassium oxide (K_2O)	(?)	(?)	(?)		....	....
Water (H_2O)	[a]15.07	[a]15.55	[a]9.36	22.01	7.00	[a]5.34
Total	99.13	99.25	98.66	100.00	99.46	99.00

[a] Loss on ignition.

1. From near Chelsea, Washtenaw County. Analysis by E. D. Campbell.
2. From near Fenton, Genesee County. Analysis by E. D. Campbell.
3. From near Farmington, Oakland County. Analysis by E. D. Campbell.
4. From near Saginaw. Analysis by H. Ries. Geol. Survey Michigan, vol. 8, pt. 1, 1900, p. 55.
5. From Wyandotte; used in cement making by the Michigan Alkali Company. Analysis by O. Button.
6. Sault Ste. Marie. Analysis by E. D. Campbell.

The river silts occur on the border of many streams, sometimes in terraces a few feet above their surfaces. Although in many instances available for brick and tile making, they are usually too sandy to be employed in manufacturing Portland cement without being ground, so as to have the requisite degree of fineness—that is, so as to pass through a sieve with 150 to 200 meshes to the linear inch. No analyses of typical examples of the river silts are available, but as the deposits are derived mainly from the drift clays, they no doubt have the same composition, lacking, perhaps, some of the calcium carbonate and alkaline salts.

In general it may be said that the surface clays of the Southern Peninsula are not favorable for use in making Portland cement, although some of the stony clays, if crushed sufficiently fine, may be employed for that purpose. Reference is not here made to the decomposed outcrop of the shales described in the preceding section, which might perhaps be taken for surface clays, some of which have been used with favorable results. In reference to the surface clays of the Northern Peninsula little accurate information is available, excepting the analysis of a representative sample of the extensive deposit of pink clay near Sault Ste. Marie, given above.

In a summary of the results of Ries's investigations of the shales and clays of Michigan, already referred to several times, A. N. Clark remarks as follows:[a]

"For use in the manufacture of Portland cement the shales of the Coldwater series are best adapted. The shales of the Michigan series are also good if not too high in

[a] Geol. Survey Michigan, vol. 8, pt. 1, 1904, p. 64.

soluble salts. Some of the Coal Measure shales, which are often too gritty, and some of the clays derived from the weathering of these shales or the Devonian black shales, may be suitable. Surface deposits of clay of any size are, almost without exception, either too calcareous and irregular in composition or too gritty to be desirable."

The difficulty of obtaining a suitable clay to use in connection with the marl deposits of the southern portion of the Southern Peninsula has led several of the Portland cement companies now in operation in that region to employ clay brought from Ohio. The most of this material comes from Milbury and Bryan and is a lacustral clay, deposited from the waters of the Erie basin (Glacial Lake Warren) when more widely expanded to the southwestward than now. Its composition is as follows:

Analyses of Ohio clays.

Constituent.	1	2
Silica (SiO_2)	[a] 62.55	61.03
Alumina (Al_2O_3)	17.46	18.10
Ferric oxide (Fe_2O_3)	5.08	6.65
Lime (CaO)	2.30	1.29
Magnesia (MgO)	1.67	.53
Sulphuric anhydride (SO_3)	Trace.	1.05
Loss on ignition	5.55	9.21
Total	98.37	89.86

[a] With the silica is included 3.76 per cent of fine sand.

1. Milbury. Analysis by E. D. Campbell.
2. Bryan. Analysis by John G. Dean and N. S. Potter, jr.

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PORTLAND CEMENT RESOURCES OF MINNESOTA.

Of the limestones occurring in Minnesota, only one is usually sufficiently low in magnesium carbonate to be worth considering as a Portland cement material. This is the limestone described as "Trenton" in the section on Iowa, pages 147–165 of this bulletin. Mr. Ulrich states that this nonmagnesian formation is well developed in southern Minnesota, particularly in the vicinity of Wyckoff and Spring Valley. The pure limestone beds in these localities are both underlain and overlain by shale, which might prove available for use in the mixture.

PORTLAND-CEMENT RESOURCES OF MISSISSIPPI.

No cement of any type has ever been manufactured in Mississippi, but several large limestone areas occur in the State, and at least one of these is so well located with respect to fuel supplies and transportation routes as to give promise of being of future importance as a source of Portland-cement material.

The available limestones of the State may be grouped and described under three heads, the third being the most promising as the possible basis of a cement industry.

The three groups noted are:

(1) Mississippian (Lower Carboniferous) limestones.

(2) Cretaceous limestones (Selma chalk or "Rotten limestone").

(3) Tertiary limestones (Vicksburg limestone).

The distribution of these formations is shown on the geologic map (Pl. II), which is based on recent work by the United States Geological Survey in Mississippi.

MISSISSIPPIAN ("LOWER CARBONIFEROUS") LIMESTONES.

In the extreme northeastern corner of Mississippi, in the counties of Itawamba and Tishomingo, there is a small area of Devonian and Carboniferous rocks. These include shales, thin sandstones, and limestones. The limestones, which are mainly of Mississippian (Lower Carboniferous) age, are frequently low in magnesia, and are otherwise suitable for use as Portland cement materials. At present, however, the most promising localities of these limestones have no adequate transportation facilities. This fact, together with the nearness of the soft and easily crushed Selma chalk, will probably serve to prevent the utilization of the Carboniferous limestones in the near future.

The following analysis of a limestone from Cypress Pond, Tishomingo County, is by Dr. E. W. Hilgard:

Analysis of Mississippian limestone.

Silica (SiO_2)	1.68
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	.58
Lime (CaO)	53.49
Magnesia (MgO)	.82
Carbon dioxide (CO_2)	42.03
Water	1.34

CRETACEOUS LIMESTONE (SELMA CHALK OR "ROTTEN LIMESTONE").

The Selma formation of the Cretaceous is a thick series of chalks, chalky limestones, and more or less limy clays, which are well exposed in northwestern Mississippi. The area occupied by these limestones is shown on Pl. II, and a very detailed description of the Alabama areas of Selma chalk is given in Doctor Smith's discussion of the cement resources of Alabama in this bulletin (pp. 72–77).

Thickness.—The Selma chalk attains its maximum thickness in central Alabama, reaching a total of about 1,200 feet. Westward it decreases slightly in thickness, the well at Livingston, Sumter County, Ala., giving a total of 930 feet, while the well at Starkville, Oktibbeha County, Miss., taken in connection with surrounding outcrops, indicates a thickness of at least 700 feet. As the belt turns northward toward Tennessee the Selma formation decreases rapidly in thickness, while at the same time the limestone beds contained in the formation become fewer and thinner, until in Tennessee the Selma is a thin series of somewhat calcareous clays, with only occasional beds of chalk.

Stratigraphy.—Owing to the rapidity with which it disintegrates when exposed to atmospheric action, surface outcrops give comparatively little information in regard to the stratigraphy of the Selma formation. Fortunately a very precise section of the Selma chalk, taken at a point where it is almost of maximum thickness, is in existence. This is embodied in the record of a well drilled at Livingston, Sumter County, Ala., and quoted by Dr. E. A. Smith in his Report on the Geology of the Coastal Plain of Alabama, pages 277–278. The well was located just south of the boundary between the Selma and Ripley formations, and reached a depth of 1,062 feet, so that it passed through the entire thickness of the Selma chalk and into the underlying Eutaw formation.

The section of this well is given below. The upper 20 feet are, according to Smith, probably in part Lafayette and in part Ripley. From a depth of 20 to 950 feet the well was in the Selma formation, while from 950 to 1,062 feet it was in the Eutaw.

Section of well at Livingston, Sumter County, Ala.

	Thickness.	Depth.
Lafayette and Ripley:	*Feet.*	*Feet.*
Sandy loam	1	
Coarse, dry sand	12	1 - 13
White quicksand	7	13 - 20
Selma chalk:		
Soft blue limestone, many shells and pyrite nodules	180	20 - 200
White limestone, harder, few shells or pyrite nodules	50	200 - 250
Hard blue limestone, no shells or nodules	7	250 - 257
Bluish-white limestone, less hard, no shells or nodules	68	257 - 325
White limestone, very hard	55	325 - 380
Light-blue limestone, softer	47	380 - 427
Bluish-brown rock, small shells, some sand	58	427 - 485
Hard, white limestone	105	485 - 590
Soft, reddish-brown rock	2	590 - 592
Soft, deep-blue rock	20	592 - 612
Brownish-blue rock, moderately soft	78	612 - 690
Hard, gritty, blue rock	½	690 - 690½
Dark-bluish rock, soft	9½	690½- 700
Soft, whitish limestone	250	700 - 950
Eutaw sands:		
Hard sandstone	6	950 - 956
Sand	10	956 - 966
Sand rock	1	966 - 967
Coarse greensand	38	967 -1,005
Sandstone	2	1,005 -1,007
Greensand	25	1,007 -1,032
Sandstone	2	1,032 -1,034
Coarse greensand	18	1,034 -1,052
Flint rock	1	1,052 -1,053
Very fine greensand	9	1,053 -1,062

Descriptions of localities.—During 1904 the Selma chalk was carefully mapped throughout the Tombigbee River basin by Mr. A. F. Crider. The result of this mapping is shown on Pl. II.

In the following pages descriptions will be given of the various localities visited during this work. Samples were taken from all of these localities, and many of these samples have been analyzed, the results being given below.

The descriptions are given in order, going up the Tombigbee River from the Alabama-Mississippi line.

The following four analyses, by Prof. W. F. Hand, State chemist, are of samples of limestone from various points in Oktibbeha County, Miss.:

Analyses of Selma limestone from Oktibbeha County, Miss.

	1	2	3	4	Average.
Silica (SiO_2)	2.89	2.33	3.03	2.55	2.70
Alumina (Al_2O_3), Iron oxide (Fe_2O_3)	1.53	1.72	1.92	1.96	1.78
Lime carbonate ($CaCO_3$)	94.10	94.35	93.60	94.07	94.03
Magnesium carbonate ($MgCO_3$)	1.84	1.82	1.64	2.12	1.85
Water	.36	.44	.42	.52	.44

At the big elbow-bend in Oaknoxubee River, a quarter mile below the wagon bridge at Macon, the river has formed a bluff 75 feet high on the south side of the stream. The entire cliff is made up of the Selma chalk. It is a solid mass of white chalk, nonfossiliferous, and apparently without bedding planes, but viewed at a distance the stratification of the material is shown by the unequal hardness of the strata, causing some to weather more rapidly than others. There is a marked dip to the south. All the smaller streams flowing into Oaknoxubee have channeled their beds into the pure white limestone. A sample was collected from the bluff on the Oaknoxubee River.

The following analysis of this sample was made by H. C. McNeil in the laboratory of the United States Geological Survey:

Analysis of Selma limestone from near Macon, Miss.

Silica (SiO_2)	9.09
Alumina (Al_2O_3), Iron oxide (Fe_2O_3)	7.47
Lime carbonate ($CaCO_3$)	80.99
Magnesium carbonate ($MgCO_3$)	.00
Water	1.08

The town of Scooba is in the Flatwoods area, which is underlain by clays of the Midway group. The road from Scooba to Dekalb is through the Midway until Sucarnooche Creek is reached, 2 miles east of Dekalb. The hills of the Laramie formation begin just west of the creek and rise 250 feet above the creek, barometric reading.

The material here forming the Midway is a gray, plastic, nonfossiliferous clay ("popping clay"). It makes a cold soil, very sticky and plastic when wet, and when it dries out it cracks open so that one can thrust his hand 6 or 8 inches into the opening.

But little of the Flatwoods area is cleared and put in cultivation, and this only where there is a little remnant of Lafayette sand left. The Lafayette formation is practically wanting over the entire area of the Flatwoods.

The timber is short-leaf pine, post oak, scrub hickory, black-jack, and black gum, with an occasional white oak and holly.

The town of Dekalb is near the east edge of the Lagrange formation. One and a half miles northeast of the town, on Sucarnooche Creek, is a bed of lignite 3 feet thick, which outcrops a few feet above the bed of the creek. This bed has been opened up with a view of developing the vein. A level was run 20 feet into the hill and considerable lignite taken out. It was found to be of excellent quality, and was burned in the office of the chancery clerk, Mr. S. O. Bell, at Dekalb. The following analyses were made, No. 1 by J. C. Long and No. 2 by R. T. Pittman.

Analyses of lignite from Dekalb, Miss.

	1	2
Fixed carbon	41.83	40.80
Volatile matter	46.82	41.48
Ash	7.94	17.64
Moisture	2.13	n. d.
Sulphur	1.28	1.57
Specific gravity	n. d.	1.33

The lignite is overlain by a bed of gray clay and this by stratified red, yellow, and white sand, with occasional bands of ferruginous sandstone in the sand. On these hills there is a deposit of Lafayette that reaches in places a thickness of 20 feet, and in this there is considerable sandstone.

The Lagrange around Dekalb—the eastern edge of the formation and therefore made up of its basal beds—is a mass of unconsolidated sand and sandy clay, which is easily eroded. The country is rough, being cut up into deep ravines and narrow valleys.

The hillsides, when properly taken care of, are fertile, and the uncleared land has a fine growth of pine, poplar, white oak, and hickory.

Two and one-half miles east of Scooba, on the west bank of the creek shown on the map (Pl. II), is the first outcrop of Selma chalk on the Scooba and Gainesville road.

A sample of limestone was taken from this outcrop by A. F. Crider and was analyzed by W. S. McNeil, in the laboratory of the United States Geological Survey, with the following result:

Analysis of Selma limestone from near Scooba, Miss.

Silica (SiO_2)	16.48
Alumina (Al_2O_3) Iron oxide (Fe_2O_3)	6.97
Lime carbonate ($CaCo_3$)	74.34
Magnesium carbonate ($MgCo_3$)	.67
Water	.67

There is a change in the character of timber as soon as the Selma area is reached. Short-leaf pine, which occurs so abundantly in the Flatwoods, is wanting except in the old "turned-out land." Black oak is the principal timber in the Selma chalk. Some post oak and hickory occur. The pine is wanting at a distance of 2 miles east of Scooba, which would perhaps bring the contact between the Selma and Midway one-half mile west of the Selma outcrop.

Two miles east of Scooba and one-half mile south is another outcrop of limestone, more sandy than that 2½ miles east of Scooba. This is perhaps of Ripley age.

Between Portersville and Oakgrove, in southern Kemper County, on the west side of Pittiefaw Creek, the Lagrange hills begin and extend westward. On land belonging to Mr. M. L. Nailer a bed of lignite, reported to be 4 feet thick, has been opened.

Sucarnooche Creek marks the west edge of the Midway group from 2½ miles due east of Dekalb to about 3 miles north of Oakgrove. Here the Porters Creek area widens and its west edge swings in to within 2½ or 3 miles east of Oakgrove, then follows a southeasterly direction and crosses the Kemper and Lauderdale County line about 3½ miles west of the State line.

On the west side of Quilby Creek, where it runs south along the State line, 7 miles east of Sucarnooche, the Selma chalk forms a small bluff. The prairie soil extends back for 2 miles farther west. On the east side of the creek, about 100 yards in Alabama, the Selma chalk forms a bluff a little higher than on the opposite bank in Mississippi. Here what is taken to be the top of the Selma chalk is found. The top of the bluff is capped by a coarse-grained sandstone, cemented by lime carbonate. In it are lime concretions the size of a closed hand.

The upper beds of the Selma chalk also appear in the bluff on the east side of Quilby Creek, 7 miles east of Sucarnooche.

An outcrop of Selma chalk shows on Scooba and Fox Prairie road where it crosses Bodea Creek, about 2 miles west of the State line.

A sample collected from this outcrop by Mr. Crider was analyzed in the laboratory of the United States Geological Survey by W. S. McNeil.

Analyses of Selma limestone from Bodea Creek, Mississippi.

Silica (SiO_2)	10.60
Alumina (Al_2O_3) Iron oxide (F_2O_3)	5.90
Lime carbonate ($CaCO_3$)	82.47
Magnesium carbonate ($MgCO_3$)	Tr.
Water	.82

Three miles north of Scooba the west border of the Selma chalk outcrops in a series of hills forming the south bank of Wahalak Creek. The bottom of the Wahalak is here 1½ miles wide, the south bank retreating more rapidly than the north side. The creek has cut its

channel into the Selma chalk, which outcrops almost continuously throughout its course. The limestone occurs up the creek about 6½ to 7 miles northwest of the town of Wahalak, but the Porters Creek clay occupies the country on either side of the creek. The hill just east of Wahalak is of Porters Creek clay, which is not over 15 feet thick.

A sample of limestone was collected by A. F. Crider from the bed of Wahalak Creek, about 1½ miles south of Wahalak. This sample was analyzed by W. S. McNeil in the laboratory of the United States Geological Survey, with the following results:

Analysis of Selma limestone from near Wahalak, Miss.

Silica (SiO_2)	20.00
Alumina (Al_2O_3) Iron oxide (Fe_2O_3)	8.92
Lime carbonate	68.91
Magnesium carbonate	Tr.
Water	1.03

A sample of the Selma limestone was taken from the bed of Wahalak Creek, 1½ miles south of the town, and on the range of low hills on the south side of Wahalak Creek, 1½ miles southeast of the point where the Mobile and Ohio Railroad crosses the creek, another sample was taken.

At the top of the Selma chalk there is about 10 feet of a sand rock cemented with lime carbonate, which contains numerous little bivalve shells. This is the same kind of stone as that found 7 miles east of Sucarnooche. There is no evidence of any Midway limestone anywhere from Wahalak to the Alabama line, and this is the only place where the sandstone was seen in Mississippi.

The Midway or Flatwoods clay is well shown near Scooba, Miss. A sample collected by A. F. Crider was analyzed by W. S. McNeil in the laboratory of the United States Geological Survey. The result is of interest because clays of this type occur everywhere near the western edge of the Selma limestone area, and such clays will be needed to reduce the percentage of lime carbonate found in some of the purer samples of Selma chalk.

Analysis of Midway clay from Scooba, Miss.

Silica (SiO_2)	61.92
Alumina (Al_2O_3)	19.47
Iron oxide (Fe_2O_3)	2.81
Lime (CaO)	.00
Magnesia (MgO)	1.98
Soda (Na_2O)	.50
Potash (K_2O)	.00
Loss on ignition	12.29

A sample of Selma chalk was taken from an old rock quarry situated on the southwest side of Bogue Chitto Creek, one-half mile east of Prairie Rock. This limestone differs from that along Oaknoxubee River, in the vicinity of Macon, in that it is much harder. In the unweathered state of the Macon rock, it is very soft and noncrystalline. One can easily stick a pick into it. But the limestone at Prairie Rock is a hard so-called "flint rock," crystalline in character, and is used for building purposes. The rock at Macon, when exposed to the weather, becomes white as chalk, that at Prairie Rock weathers to a dirty gray and contains some traces of iron stain on the weathered surfaces. This is due to the oxidation of the iron sulphide (pyrite), which is found in small concretions in the fresh rock.

An analysis of this Prairie Rock limestone, made by W. S. McNeil, in the laboratory of the United States Geological Survey, follows. It will be seen that the stone is a very pure limestone, in spite of the manner in which it discolors on weathering.

Analysis of Selma limestone from Prairie Rock, Mississippi.

Silica (SiO_2)	1.13
Alumina (Al_2O_3) Iron oxide (Fe_2O_3)	.68
Lime carbonate ($CaCO_3$)	98.36
Magnesium carbonate ($MgCO_3$)	tr.
Water	.40

The rock breaks down easily when exposed to the weather, and hence is not now used for extensive building purposes. It is, however, the only road material found in this section of the country. It has been used on the road across Bogue Chitto swamp, but is unsatisfactory.

Men familiar with the country say that this hard limestone is very thin—only about 4 feet thick—and occurs near the surface. Below this hard stratum comes the soft, whiter "rotten limestone," which is, on an average, 20 feet thick. Below this comes the "blue rock," which holds water. In digging cisterns, the farmers always dig down to the "blue rock," which requires no curbing.

There are two kinds of soils in the prairie section, the "post-oak" land and the "prairie" proper. The former is the highest land between the stream divides, which has suffered but little erosion. It is very level, sloping gently to the streams. This post-oak land is covered with a thin coating of Lafayette, clayey sand, never over 10 feet thick, which has never been all carried away by erosion. The uncleared land produces post-oak and some black-oak timber.

The "prairie" land is that from which the Lafayette has been removed, and the black, rich loam, formed from the decomposition

of the Selma chalk, comes to the surface. The limestone never comes to the surface except along the streams.

When the country was first settled this black prairie soil was too strong for cotton. It produced a large stalk, but very little cotton. Until recent years all the cotton was planted on the poorer "post-oak" lands, and the prairie lands were put in corn. But after years of continuous crops of corn the prairie land became the best cotton land, and now the finest cotton grows on the prairie lands.

Later investigation around Columbus and Aberdeen has verified the fact that the land known by all as the "post-oak land," as distinguished from the black "prairie soils," is the land from which the entire Layfayette has not been removed. The soil is not so rich as the prairie soils, and has been largely abandoned for cultivation.

The following well sections are of interest in this connection:

Well at Ravine, on land of J. Q. Poindexter.

	Feet.
Selma chalk	250
Sand, water bearing, and principal source of water	475
Red clay	50
Depth	725

Water rises within 26 feet of surface. Water soft.

Well 2 miles due east of Ravine, on Sebe Gavin's land.

	Feet.
Depth of well	431

Water flows 16 feet above surface.

Well on Doctor Patty's land, near Bigbee Valley post-office.

	Feet.
Depth of well	431

Water flows 20 feet above surface. Water found in sand, and soft.

Well at Bigbee Valley post-office, sec. 16, T. 16, R. 19 E.

	Feet.
Depth of well	460
Thickness of Selma chalk	200

Water flows 20 feet above surface.

Well in sec. 21, T. 16, R. 19 E.

	Feet.
Depth of well	444
Thickness of sand	200

Flows.

Well at Cliftonville.

	Feet.
Limestone	300
Dark sand, dry	20
White sand, water-bearing	20
Dark sand, dry	10
White sand, water-bearing	40
Ferruginous sandstone	1

Depth of well, 450 feet; 300 feet in limestone, 150 feet in sand.
Source of water, green sand.

Well on A. G. Cunningham's land, 1½ miles west of mouth of James Creek.

	Feet.
Depth of well	500
Thickness of limestone	100

Well is 75 feet above Tombigbee River. Water overflows.

Well at Pickinsville, Ala., on land of Will Rodgers.

	Feet.
Thickness of limestone	100
Depth of well	400

Flows.

All wells mentioned above except the first one were drilled by J. B. Cunningham, Cliftonville, Miss., and the records were obtained from him. The well drillers fail to make any distinction between the lower Selma and the upper Eutaw, so that their records can not be depended upon for determining the thickness of the Selma.

A sample of sandy limestone was obtained from the mouth of James Creek, on Tombigbee River. Along the Tombigbee at the mouth of James Creek there is an exposure of a green-sand clay containing a large amount of lime. Fifty feet above the river, 1½ miles west of the mouth of James Creek, another sample of limestone was collected. The limestone here is similar in color and general aspect to that on Tombigbee, except that it has less green sand.

Farther west the limestone rarely shows at the surface. It is clayey in character and easily dissolved by the weathering agents, so that it breaks down into soil faster than it is carried away by erosion.

At Cliftonville, which is 75 feet above Tombigbee River (barometric reading), there is a hard cap rock, 2 to 4 feet thick, found on top of the hills in the vicinity of the town. This a hard "lime" rock, similar to that found at Prairie Point.

Below this hard cap rock comes what is called the "blue rock." A sample of it seen at a well dug years ago shows that it is similar to the rock at Cunningham Hill, except that it contains no sand. Where the blue rock comes to the surface it forms a belt of the richest soil in the prairie region. The soil is very deep, black, and loose. More cotton and corn are raised to the acre here than in any other section of the State.

West of this region the land becomes higher, and the Lafayette occupies the surface on the ridges.

Six miles north of Macon, on the Macon and Columbus road, the limestone begins to show at the surface in small gullies. The rock is harder than the blue rock along the Tombigbee, and therefore occurs more frequently.

A sample collected from this locality by A. F. Crider was analyzed by W. S. McNeil in the laboratory of the United States Geological Survey.

Analysis of Selma limestone from locality north of Macon, Miss.

Silica (SiO_2)	8.52
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	6.60
Lime carbonate ($CaCO_3$)	83.88
Magnesium carbonate ($MgCO_3$)	.00
Water	1.00

Farther south, along the Macon and Columbus road, the limestone begins to show in every gully and on every hillside. At some places on level ground the soil is not over 12 inches deep. In this vicinity are the bald prairies, where large areas of this white limestone are exposed without a particle of soil or a blade of grass. A sample of the rock was taken 3 miles north of Macon.

A sample of Selma limestone was taken at a point north of Lime Rock, 5 miles east of Shuqualak, on Oaknoxubee River, where a bluff 50 feet high is composed of typical Selma chalk. The following analysis of this sample was made by W. S. McNeil, in the laboratory of the United States Geological Survey:

Analysis of Selma limestone from near Shuqualak, Miss.

Silica (SiO_2)	8.06
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	5.94
Lime carbonate ($CaCO_3$)	84.61
Magnesium carbonate ($MgCO_3$)	.06
Water	1.32

The Tombigbee River at Columbus has cut its channel into the Eutaw sands, forming a bluff on the east side 90 feet high. The material composing the bluff here is a sand that is greenish when wet and gray when dry. It contains a small amount of lime carbonate. At the upper part of the bluff the sands are of lighter color, and at the top are of a light golden yellow. This was the color of sand when deposited, and is not due to oxidation. Numerous little branching concretions, which are perhaps some kind of badly preserved fossils, occur in the lower portion near the water. The upper part of the sands contain two species of large oysters, which also occur in the Selma. The river at the town is now hugging the east bluff, and the bottom, which is 3 miles wide, is all on the west side. A short distance above the town, however, the reverse is true, the bluff being on the west side and the bottom on the east.

At the west edge of the bottom the heavy, black prairie soils of the Selma chalk appear as soon as the little hills are reached. The bottom extends northward to the little creek that flows northeastward into the river 3 miles above the town.

At a distance of 4 miles above town the bluff on the west side of the river reaches about the same height above the stream as the bluff at

Columbus. It extends for 1 mile along the river as a perpendicular cliff that affords a fine section of the upper Eutaw and the base of the Selma. At the top of the bluff, the low hills on the west come down to the river. The same heavy, black prairie soils which come within 3 miles of the river due west of Columbus, here come down to the edge of the bluff.

The following is a section of the bluff obtained where the road comes down to the river:

Section of bluff of Tombigbee River 3 miles west of Columbus, Miss.

		Feet.	In.
Lafayette at top.			
Selma:			
	"Blue rock" of the Selma; a white to gray joint clay containing less sand at top than at bottom. In its unweathered condition the clay is pale blue, with green and black sand	10	8
Eutaw:			
	Green sand, highly calcareous, and containing numerous large oysters	9	5
	Indurated ledge of greensand, calcareous, and containing same fossils as No. 9	8	12
	Lighter colored sand, containing very few small fossils but no large ones	7	14
	Green sand, nonfossiliferous	6	6
	Slightly fossiliferous, gray micaceous sand	5	5
	Indurate ledge, slightly fossiliferous sand	4	10
	Green sand, containing same large oysters as No. 9	3	4
	Indurate ledge	2	8
	Fossiliferous greensand to the water's edge	1	4

The prairie soil of the Selma extends to the river north of Columbus, but is not found east of the river. From Columbus south to the south side of M. C. Gower's creek on the west side of the river the Tombigbee bottom ranges in width from 2 to 4 miles. South of this creek the bottom changes again to the east side, and the Selma extends to the river.

At the mouth of James Creek the same joint clay that is seen above Columbus occurs on the east bank of the creek, about 10 feet above the water's edge.

Eight miles east of Columbus, on the Columbus and Tuscaloosa road, the hills of the Tuscaloosa formation first appear. On the hill near the 8-mile post the highly stratified clay, interbedded with various colored sands, outcrops on the side of the road.

At Stiens Station the creek is cutting into the Eutaw sands.

Where the road crosses Yellow Creek the foundation of the bridge is built on the compact sand, which here is of a deep-gray color and very homogeneous in character.

One mile south of Strongs, on the Illinois Central Railroad, on the Monroe and Clay line, the railroad has cut into the Selma clay to a depth of 15 feet.

Eutaw sands extend west of the town of Aberdeen for 2 miles. Here the post-oak lands begin, and the regular prairie soils one-half mile farther west. There are no outcrops of Selma from Aberdeen to Prairie Station. The first outcrop found northwest of Aberdeen is at Strongs. Outcrops of Selma here, as farther south, are very few on the east edge of Selma.

The following analysis of a sample of the Selma chalk from near Okolona, Chickasaw County, Miss., is an old one, made by Doctor Hilgard.[a] Of the material reported as "insoluble," probably about two-thirds was silica, the remainder being alumina and iron oxide.

Analysis of limestone from Okolona, Miss.

Insoluble (mostly silica, SiO_2)	10.90
Alumina (Al_2O_3)	1.98
Iron oxide (Fe_2O_3)	1.42
Lime (CaO)	[b]45.79
Magnesia (MgO)	[c].88
Alkalies (K_2O, Na_2O)	.57
Carbon dioxide (CO_2)	35.73
Water and organic	2.84

TERTIARY LIMESTONES (VICKSBURG LIMESTONE).

A narrow belt of limestone of Tertiary age crosses the State in a direction a little north of west, from near Waynesboro to Vicksburg. This is the Vicksburg limestone, which is equivalent to the upper part of the St. Stephens limestone of Alabama. The relations which exist may be indicated as follows:

Mississippi.	Alabama.
Vicksburg limestone ..... Jackson marls and clays..	=St. Stephens limestone.

A very detailed description of the characters and composition of the St. Stephens limestone, as shown in its Alabama outcrop, is given by Doctor Smith on pages 77 to 81 of this bulletin, while on Pl. II the outcrop across Alabama and Mississippi of the St. Stephens and the Vicksburg-Jackson is indicated.

In Mississippi the Vicksburg limestone usually outcrops in a low ridge that trends generally a little north of west. The southern slope of this ridge is gentle, but its northern face is a sharp declivity, which makes it easy both to locate the outcrop and to quarry the limestone.

The Vicksburg limestone carries usually from 80 to 95 per cent of lime carbonate, with very little magnesium carbonate. Occasionally, however, more clayey phases are encountered, but in general this formation may be everywhere regarded as a possible source of Portland cement material.

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[a] Report on the Geology of Mississippi, p. 101. 1860.
[b] Equals lime carbonate ($CaCO_3$), 81.77.
[c] Equals magnesium carbonate ($MgCO_3$), 1.84.

The analysis below, by Mr. G. T. Hetherington, was recently made on a sample taken several miles south of Jackson, Hinds County:

Analysis of Vicksburg limestone from near Jackson, Miss.

Silica (SiO_2)	9.63
Alumina (Al_2O_3)	2.73
Iron oxide (Fe_2O_3)	2.76
Lime (CaO)	45.95
Magnesia (MgO)	.99
Alkalies (K_2O, Na_2O)	.95
Sulphur trioxide (SO_3)	.35
Carbon dioxide (CO_2), Water	37.00

This corresponds to a content of about 81 per cent lime carbonate; and as the rock is otherwise satisfactory, the addition of a little clay will make a suitable Portland cement mixture.

The analyses below were published in the early reports of the Mississippi Geological Survey. The last two, and perhaps the other three also, were made by Dr. E. W. Hilgard.

Analyses of Vicksburg limestones from Mississippi.

	1	2	3	4	5
Silica (SiO_2)	6.30	15.05	9.20	2.03	12.31
Alumina (Al_2O_3), Iron oxide (Fe_2O_3)	7.20	5.35	6.65	2.12	2.70
Lime (CaO)	48.44	44.58	47.12	52.47	43.93
Magnesia (MgO)	n.d.	n.d.	n.d.	.67	1.69
Alkalies (K_2O, Na_2O)	n.d.	n.d.	n.d.	n.d.	.79
Sulphur trioxide (SO_3)	n.d.	n.d.	n.d.	n.d.	1.27
Carbon dioxide (CO_2)	38.06	35.02	37.03	41.53	34.72
Water	n.d.	n.d.	n.d.	1.10	2.40

1-3. Red Hills, Wayne County. Harper, Report on Geology of Mississippi, 1857, p. 166.
4. Brandon, Rankin County. Hilgard, Report on Geology of Mississippi, 1860.
5. Byram, Hinds County. Hilgard, Report on Geology of Mississippi, 1860.

PORTLAND-CEMENT RESOURCES OF MISSOURI.

PORTLAND-CEMENT MATERIALS.

Two large Portland-cement plants are now in operation in Missouri, and it seems probable that this State will soon become an important factor in the cement production of the United States. This probability of high rank as a cement producer is due to the fact that the thickest and purest limestones of the State outcrop along the banks of the Mississippi and Missouri rivers. Plants located on these lime-

stones are therefore assured of cheap fuel and water and rail transportation to a number of important cement markets.

The Missouri limestones which are best adapted for use as Portland-cement materials are of Mississippian and of Trenton (Ordovician or Lower Silurian) age. The Cambrian limestones, which cover nearly all of southeastern Missouri, are almost always too high in magnesia to be worth considering in this connection. The nonmagnesian Silurian limestones occurring along the Mississippi between Chester, Ill., and Cape Girardeau, Mo., however, are worth investigation.

The geologic relations of these limestones, and of the shales and clays which will be required for mixture with them, are indicated in the following table. This table shows the portion of the geologic column of Missouri that is of interest in this connection, the oldest rocks being those placed at the bottom.

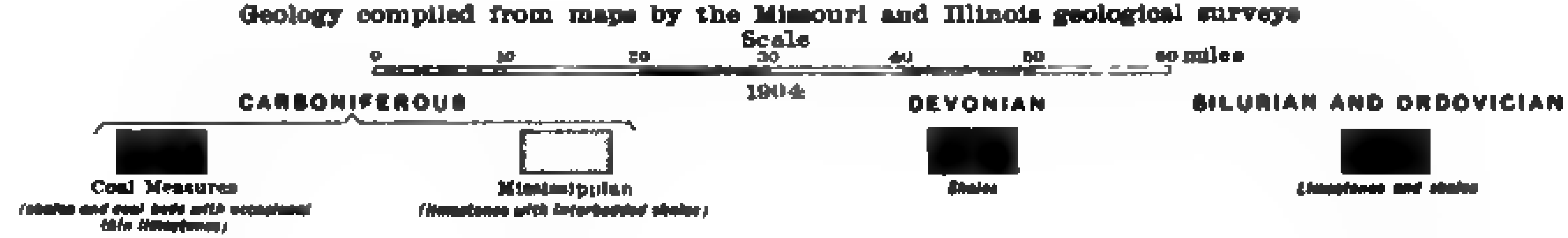
Portion of geologic column of Missouri.

Quaternary		Loess and surface clays.
Carboniferous	Upper Coal Measures	Shales, sandstones, etc.
	Lower Coal Measures	Coal beds, shales, etc.
	Mississippian	Limestones, sandstones, and shales.
Devonian		Dark-colored shales.
Silurian		Magnesian limestones in part.
Upper Ordovician	Girardeau limestone	Shale and sandstone.
	Thebes formation, or late Ordovician shale	Shale and sandstone.
	Trenton	Limestone.
Lower Ordovician and Cambrian		Magnesian limestones, sandstone, etc.

The formations listed above will now be described in order, from the Trenton upward, attention being paid mainly to the Trenton and Mississippian, which contain most of the nonmagnesian limestones occurring in the State. A detailed map showing the geology of northeastern Missouri is given as Pl. IX. In the following descriptions attention will be paid chiefly to their distribution and composition of the formations in the area covered by this detailed map, for it is in this portion of Missouri, along or near Mississippi River, that the best prospects for a Portland-cement industry exist. Southeastern Missouri, as already noted, has practically no limestones fit for use as Portland-cement materials, except along the Mississippi River to Cape Girardeau. The western half of Missouri contains extensive areas of Mississippian limestones, but a cement plant located in that portion of the State would be brought into direct competition with the existing Kansas plants, which have the advantage of a cheap fuel—natural gas.

GEOLOGIC MAP OF NORTHEASTERN MISSOURI AND SOUTHWESTERN ILLINOIS

Geology compiled from maps by the Missouri and Illinois geological surveys



TRENTON LIMESTONE.

DISTRIBUTION.

The Trenton limestone occurs in two separate areas in eastern Missouri, both of which are well located with regard to railroad and water transportation.

The smaller of these areas lies in Ralls, Pike, and Lincoln counties, the limestone outcropping as a belt 1 to 3 miles wide, commencing near Spalding, Ralls County, and running southeastward to Mississippi River, which it reaches at a point near Busch, about 10 miles south of Hannibal. From this point southward the Trenton limestone belt follows the river to near Cap au Gris, Lincoln County, where it turns sharply back in a northwesterly direction to within a few miles west of Edgewood, Pike County.

The second and much larger belt commences in southern Callaway County, and runs eastward parallel to and a few miles north of Missouri River, through Montgomery, Warren, and St. Charles counties. This belt reaches the Missouri River at Hamburg, St. Charles County, and turns southeastward through St. Louis and Jefferson counties, reaching the Mississippi River at Kimmswick. From this point south to Cape Girardeau the limestone follows the river closely, appearing either in the bluffs or only a few miles west of them.

COMPOSITION.

The Trenton limestones are usually bluish to gray colored in the lower part, and light colored—sometimes almost white—in the upper part, with occasional thin beds of shale or earthy limestone between these two parts. As shown by the analyses in the following table, they are usually low in magnesia, and though occasional beds may show 5 to 10 per cent of magnesium carbonate the mass of the formation may be regarded as being suitable for use as a Portland-cement material.

Analyses of Trenton limestone from Missouri. [a]

	1	2	3	4	5	6	7	8	9	10
Silica (SiO_2)	0.35	12.15	2.25	0.45	6.00	1.00	0.46	0.70	0.35	0.55
Alumina (Al_2O_3), Iron oxide (Fe_2O_3)	.35	.45	.30	.65	1.05	.55	.40	.25	.30	.60
Lime carbonate ($CaCO_3$)	97.75	86.00	89.40	97.20	82.55	96.40	98.60	97.40	97.75	96.75
Magnesium carbonate ($MgCO_3$)	.45	.46	6.96	.46	9.27	.42	.34	.42	.27	.27

1. Dorenheim quarry, St. Paul, St. Louis County.
2. Thorn & Hunkin quarry, Minck station, St. Louis County.
3. Glencoe Company, south quarry, Glencoe, St. Louis County.
4. Glencoe Company, middle quarry, Glencoe, St. Louis County.
5-10. Glencoe Company, north quarry, Glencoe, St. Louis County.

[a] These analyses are from Bulletin No. 3, Missouri Geol. Survey, pp. 77-79, 1890. The quarries are named according to their owners at that date. The analyses were all made by A. E. Woodward.

LATE ORDOVICIAN SHALE.

This formation is composed largely of bluish to greenish shales, often containing a large precentage of lime. North of Lincoln County thin bands of pure limestone, varying from a few inches to a few feet in thickness, are usually interbedded with the shales. These limestone bands become more numerous and thicker as the base of the formation is approached. The formation varies from 0 to over 100 feet in thickness, and immediately overlies the Trenton limestones. In its exposures near Mississippi River, in Ralls, Pike, and Lincoln counties, it is usually overlain either by Devonian shales or by the great series of Mississippian limestones described on a later page. The following analysis is of a specimen of this shale from near the base of the river bluff at Louisiana, Pike County:

Analysis of Hudson shales from Louisiana, Pike County, Mo.[a]

Silica (SiO_2)	57.01
Alumina (Al_2O_3)	24.43
Iron oxide (Fe_2O_3)	5.77
Lime (CaO)	1.40
Magnesia (MgO)	.49
Alkalies (K_2O, Na_2O)	3.81
Combined water	7.20
Moisture	.43

DEVONIAN FORMATIONS.

In the northeastern portion of Missouri (see Pl. IX) a series of dark-colored shales of Devonian age appears in places above the Hudson shales and below the Mississippian limestones. These Devonian shales vary from 10 feet or less to 50 feet in thickness. At Louisiana, Pike County, 8 feet of Devonian shales appear in the river bluffs, overlying the Hudson shale, whose analysis is given in the preceding table. In Jefferson County, as at Sulphur Springs, similar shales occur resting on the Trenton limestone, but their distribution is very irregular.

MISSISSIPPIAN ("LOWER CARBONIFEROUS") LIMESTONES AND SHALES.

DISTRIBUTION.

The Mississippian limestones are the surface formations over almost one-fourth of the entire area of Missouri. Their three most prominent areas of outcrop are along the Mississippi and Missouri rivers and in southwestern Missouri. These three areas are connected by narrow bands of outcrop so as to really form portions of one large area, but, for convenience, they will be discussed separately. The

[a] Missouri Geol. Survey, vol. 11, p. 404.

Mississippi River area, which is the most promising of the three as a source of cement material, will be discussed last and in greater detail than the others.

In southwestern Missouri the Mississippian limestones form the surface of the greater part of McDonald, Newton, Jasper, Barry, Lawrence, Stone, Christian, Greene, Dade, and Cedar counties, and also the southwestern half of Polk and smaller portions of Barton, St. Clair, Hickory, and Benton counties. This extensive limestone area is traversed by numerous railroads, but the competition of Kansas plants using natural gas for fuel would probably make a cement plant located in southwestern Missouri unsuccessful.

Another area of Mississippian limestones is on and near the Missouri River. In this area the limestones cover most of Pettis, Saline, and Cooper counties, on the south side of the river, while they outcrop continuously along the north bank of the river from Miami station, Carroll County, through southern Howard County, to below Rocheport, Boone County. The limestone belt then leaves Missouri River and turns northeastward, through Boone, Callaway, and Montgomery counties, to join the Mississippi River limestone belt discussed below.

A very extensive and important area of Mississippian limestones occurs in northeastern and eastern Missouri, along Mississippi River. This belt covers the eastern half of Clarke, all, or almost all, of Lewis, Knox, Shelby, Marion, Monroe, Ralls, Pike, Lincoln, and St. Charles counties, and portions of Montgomery, Warren, St. Louis, Jefferson, Ste. Genevieve, and Perry counties. The distribution of the limestones in these counties is shown in detail in the geologic map of northeastern Missouri (Pl. IX).

The limestones appear continuously in the river bluffs or in stream cuts along the west bank of the Mississippi, from the Iowa State line to a point about 10 miles south of Hannibal. Here the Mississippian limestones leave the river for some distance, Silurian rocks appearing in the bluffs from below Saverton to Cap au Gris. At Cap au Gris the limestones again appear, and form the river bluffs as far south as Kimmswick, in Jefferson County. Ordovician rocks then appear on the river bank for a space of about 12 miles, but about 5 miles below Crystal City the Mississippian limestones reappear in the bluffs and show almost continuously to a point less than a mile south of Wittenberg, Perry County, where they finally disappear.

COMPOSITION.

The Mississippian rocks of Missouri include several thick limestone formations, with at least one thick series of shales. The limestones, as shown in a table of analyses below, are almost invariably good Portland-cement materials.

The following section is exposed in the river bluffs at Louisiana, Pike County:

Section of river bluff at Louisiana, Pike County, Mo.

	Feet.
Surface clay, yellow	10
Mississippian:	
Burlington limestone	70
Shale, sandy	10
Hannibal shale, olive	70
Louisiana limestone	50
Devonian shale, dark, slaty	8
Silurian:	
Limestone	15
Hudson shale, blue	60

An analysis of the Hannibal shale from this locality will be found in the table on page 225.

Analyses of Mississippian limestones, Missouri.

Number.	Silica (SiO_2).	Alumina (Al_2O_3). Iron oxide (Fe_2O_3).	Lime carbonate ($CaCO_3$).	Magnesium carbonate ($MgCO_3$).
1	1.10	0.40	94.00	3.18
2	2.00	.40	95.15	.64
3	4.35	1.75	77.95	14.84
4	1.24	.37	97.71	.68
5	4.05	.37	93.21	.79
6	2.86	.35	89.26	4.73
7	3.20	.40	93.20	1.44
8	5.77	.43	89.95	2.23
9	4.71	.22	94.15	1.48
10	2.47	.31	92.30	1.88
11	.72	.60	98.06	.61
12	.15		99.64	.21
13	.08	.40	98.80	.05

1. Valley Park railroad cut, St. Louis County. Missouri Geol. Survey, Bull. 3, p. 77.
2. Vigus station quarry, St. Louis County. Ibid.
3. St. Louis, St. Louis County. Ibid.
4. Goetz quarry, Bartold Valley, St. Louis County. Ibid.
5–6. Workhouse quarry, St. Louis County. Ibid.
7–8. Lorentz quarry, near Cahokia street, St. Louis, St. Louis County. Ibid., p. 76.
9–10. Quarry, foot of Barton street, St. Louis, St. Louis County. Ibid.
11. Carthage Marble Co. W. B. Potter, analyst.
12. Star Lime Co.'s quarry, near Hannibal, Marion County. Twentieth Ann. Rept. U. S. Geol. Survey, pt. 6, p. 415.
13. Hannibal Lime Co.'s quarry, near Hannibal, Marion County. Ibid.

Analyses of Mississippian shales, Missouri.

	1	2	3	4	5	6
Silica (SiO_2)	75.70	56.82	46.26	49.69	59.97	55.84
Alumina (Al_2O_3)	9.61	24.48	10.26	17.40	21.15	22.78
Iron oxide (Fe_2O_3)	1.79	3.82	2.65	4.01	5.20	5.24
Lime (CaO)	2.54	.83	11.08	8.07	1.55	.73
Magnesia (MgO)	2.11	1.81	7.84	4.16	1.10	1.26
Alkalies (K_2O, Na_2O)	2.65	3.80	3.17	2.73	3.88	4.10
Combined water	6.16	8.16	[a]18.02	13.37	5.71	9.84
Moisture	n. d.	n. d.	n. d.	1.16	1.25	n. d.

[a] Probably includes CO_2.—E. C. E.

1. Hannibal, Marion County. Missouri Geol. Survey, vol. 2, p. 400.
2. Humansville, Polk County. Ibid., p. 406.
3. Aldrich, Polk County. Ibid., p. 407.
4. Barrett, St. Louis County. Ibid., p. 422.
5. Ste. Genevieve, Ste. Genevieve County. Ibid., p. 417.
6. Joplin, Jasper County. Ibid., p. 392.

PENNSYLVANIAN ("COAL MEASURES") LIMESTONES AND SHALES.

Almost all of northern and western Missouri is covered by the Pennsylvanian series ("Coal Measures"), which overlie the Mississippian rocks last described. The Pennsylvanian series consists of thick series of shales and sandstones, with occasional thin beds of limestone and numerous coal seams. In the present connection this geologic series is of interest chiefly as a source of fuel and shales, though it is possible that some of its limestones may be also of value as cement materials.

The following analysis is of a limestone which overlies the Meadows coal seam in Lincoln County. This limestone bed varies in thickness from 4 to 6 feet. As shown by the analysis, it is highly siliceous, though very low in magnesia. Judging from experience elsewhere, the Pennsylvanian limestones will probably be found in most cases sufficiently low in magnesia to be available for use as Portland-cement materials. They occur almost invariably in thin beds, however, and it is usually necessary to excavate them by mining. Their common advantage is, of course, that they are found in close proximity to coal beds and to shales.

Analysis of Pennsylvanian limestone, Missouri.[a]

Silica (SiO_2)	21.35
Iron oxide (Fe_2O_3)	1.79
Lime (CaO)	42.16
Magnesia (MgO)	.66
Carbon dioxide (CO_2)	34.14

[a] Lincoln County. Chauvenet, analyst. Rept. Missouri Geol. Survey, 1872, p. 287.

Analyses of Pennsylvanian shales, Missouri.

Number.	Silica (SiO_2).	Alumina (Al_2O_3).	Iron oxide (Fe_2O_3).	Lime (CaO).	Magnesia (MgO).	Alkalies (K_2O, Na_2O).	Combined water.	Moisture.
1..........	60.70	18.20	7.58	2.68	Trace.	3.67	6.77	n. d.
2..........	59.96	15.76	7.72	.60	0.93	3.66	7.70	4.00
3..........	54.57	23.61	7.88	.52	1.48	3.55	6.67	1.03
4..........	56.86	17.97	9.35	1.67	1.12	2.61	6.96	2.45
5..........	63.11	23.11	1.79	.42	.70	3.71	7.05	....
6..........	60.12	21.35	7.06	.82	1.08	3.43	6.32	....
7..........	54.69	25.96	4.97	.18	.15	3.58	8.90	....
8..........	53.24	23.62	9.02	1.17	1.41	4.38	6.94	....
9..........	58.50	30.50	2.34	1.20	.51	.30	6.74	.40
10..........	54.03	22.50	7.90	.85	2.70	4.12	7.54	....
11..........	55.96	20.63	8.12	1.91	1.96	3.34	7.32	....

1. Prospect Hill, St. Louis County. R. Chauvenet, analyst. Missouri Geol. Survey, vol. 11, p. 419.
2, 3. Laclede fire-clay mine, Cheltenham, St. Louis County. Ibid., p. 421.
4. Huntsville, Randolph County. Ibid., p. 411.
5. Billings, Christian County. Ibid., p. 375.
6. Deepwater, Henry County. Ibid., p. 387.
7. Clinton, Henry County. Ibid., p. 382.
8. Boonville, Cooper County. Ibid., p. 377.
9. Lakenan, Shelby County. Ibid., p. 424.
10. Lexington, Lafayette County. Ibid., p. 395.
11. Foster, Bates County. Ibid., p. 369.

LOESS AND SURFACE CLAYS.

Along the banks of Mississippi and Missouri rivers thick deposits of loess clays occur in the river bluffs. These are fine-grained clays, carrying a considerable percentage of very fine sand, and will be valuable for use at cement plants located near these rivers. Smaller local deposits of surface clays also occur all over the State. The table below contains analyses of representative clays of both types:

Analyses of loess and surface clays, Missouri.

	1	2	3	4	5	6	7	8
Silica (SiO_2)	73.92	73.80	72.00	71.11	74.39	61.19	62.80	54.90
Alumina (Al_2O_3)	11.65	13.19	11.97	11.62	12.03	15.48	17.22	18.03
Iron oxide (Fe_2O_3)	4.74	3.43	3.51	3.90	4.06	5.49	5.21	6.03
Lime (CaO)	1.43	.86	1.80	2.37	1.50	1.95	.98	2.88
Magnesia (MgO)	.60	.68	1.35	1.47	1.53	1.56	.78	1.10
Alkalies (K_2O, Na_2O).........	3.13	2.94	3.25	3.14	3.01	2.82	3.63	3.40
Combined water	3.08	5.26	6.42	6.71	3.17	9.02	7.82	6.90
Moisture	......	......	......	......	......	3.11	2.06	6.72

1. Loess clay, St. Louis, St. Louis County. Missouri Geol. Survey, vol. 2, p. 486.
2. Loess clay, Hannibal, Marion County. Ibid.
3. Loess clay, Kansas City, Jackson County. Ibid.
4. Loess clay, Boonville, Cooper County. Ibid.
5. Loess clay, Jefferson City, Cole County. Ibid.
6. Gumbo clay, Elm Point, St. Charles County. Ibid., p. 548.
7. Gumbo clay, Clifton, Randolph County. Ibid., p. 547.
8. Gumbo clay, Norborne, Carroll County. Ibid., p. 546.

PORTLAND-CEMENT INDUSTRY IN MISSOURI.

Prior to the year 1902 no Portland-cement plants existed in Missouri. In that year, however, the St. Louis Portland Cement Company commenced operations, while in 1903 the Atlas Portland Cement Company began shipping. Several other plants have been planned, but at present the two above named are the only ones in operation.

The plant of the St. Louis Portland Cement Company is located at Prospect Hill station, near the northern limits of the city of St. Louis. The limestone used is of Mississippian age, and is quarried at Fort Bellefontaine.

Shales of Coal Measures age are quarried near the plant and, together with the loess clays which overlie them at this locality, are used for mixing with the limestone.

The plant of the Atlas Portland Cement Company is located at Ilasco, Pike County, a few miles south of Hannibal. The materials used are a Mississippian limestone, from a quarry adjoining the mill, and a shale quarried near Severton. This shale is probably of Ordovician age, the Hannibal (Mississippian) shales near the plant being apparently unfit for use. Selected specimens of the limestone used analyze as follows:

Analyses of Mississippian limestone, Ilasco, Mo.

	1	2
Silica (SiO_2)	0.40	0.54
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	.44	.42
Lime carbonate ($CaCO_3$)	97.99	97.74
Magnesium carbonate ($MgCO_3$)	.42	.40

CEMENT RESOURCES OF MONTANA.

By W. H. Weed.

Limestone is confined practically to the western, mountainous part of the State, where it is found in great abundance along the flanks of the mountain ranges. In the Plains region, which comprises the eastern two-thirds of the State, only Cretaceous rocks are found, except in the local dome-shaped uplifts of the Little Rock, Judith, and Snowy mountains. The Cretaceous formations hold lenses and concretions of limestone, which are locally available for burning to quicklime where better material is too far distant for economic use.

All the Paleozoic formations contain limestone beds, but the great limestone series is that of the Carboniferous (Mississippian), whose

massive beds flank the great ranges of the State and form its most picturesque scenery. The overlying Jurassic limestone is argillaceous and of uncertain development. The Devono-Silurian limestones are impure, while the Cambrian limestones are thin bedded and usually not uniform in composition.

The limestones are found along the northern slope of the mountain front from Red Lodge, in Carbon County, westward to Livingston, northward about the flank of the Bridger and Little Belt and Belt ranges to the Main range west of Great Falls. Practically all the southern ranges of the western part of the State are uplifts with cores of gneiss or granite mantled by limestones of various ages. Such rocks occur westward almost to the Bitterroot Valley.

North of the line of the Northern Pacific Railroad the Carboniferous limestones soon disappear, though the Cambrian rocks form the mountain summits almost to the Canadian line. The northwestern part of the State, however, is composed mostly of Algonkian rocks, mostly argillaceous. A series of oolitic limestones, the Newland limestone, forms a constant feature of this Belt terrane, but nothing is known of the composition of these rocks save that they are usually quite argillaceous.

The following analyses of Montana limestones are on record:

Analyses of limestones, Montana.

	1	2
Silica (SiO_2)	1.45	0.40
Alumina (Al_2O_3)	.16	4.45
Iron oxide (Fe_2O_3)	.76	.20
Lime (CaO)	49.42	52.15
Magnesia (MgO)	2.74	1.02
Carbon dioxide (CO_2)	41.73	42.07

1. Persell Limestone Company, near Helena. E. Starz, analyst.
2. Montana Marble and Mining Company, near Helena. C. M. Fassett, analyst.

Both of the above analyses, but particularly the first, represent limestones whose composition would be very satisfactory from the Portland cement manufacturers' point of view.

PORTLAND-CEMENT RESOURCES OF NEBRASKA.

The possible sources of cement materials in Nebraska are confined to the formations of Carboniferous and Cretaceous age. Named in order, from above downward, these include the following:[a]

Cretaceous	Laramie formation	Yellowish and greenish sandstone and shale.
	Pierre clay	Dark-gray clay or soft shale.
	Niobrara formation	Chalky limestone.
	Benton shale	Dark-gray or black shale or clay.
	(Greenhorn limestone)	(Limestones in Benton shale.)
	Dakota sandstone	Brown sandstone.
Carboniferous	Permian limestone	Buff limestones and shales.
	Cottonwood limestone	Massive light-colored limestone.
	Wabaunsee formation	Limestones, shales, sandstones, and thin coal beds.

CARBONIFEROUS FORMATIONS.

The Carboniferous limestones, shales, and sandstones underlie all of Nebraska, rising to the north and northwest about the Black Hills and and on the slopes of the Rocky Mountains. The outcrops in eastern Nebraska are in Douglas, Sarpy, Cass, Lancaster, Otoe, Gage, Johnson, Pawnee, Nemaha, and Richardson counties. The rocks are hard and would give rise to more prominent features in this region if it were not for the heavy covering of glacial drift and loess. As it is, the exposures constitute cliffs along Platte River from Ashland to Plattsmouth, and thence at intervals along Missouri River to the southeast corner of the State, and occur in scattered outcrops along the valleys of Big Blue, Nemaha, and Little Nemaha rivers and Weeping Water, Turkey, and Southeast Salt creeks and their branches.

The Upper Carboniferous rocks in this region comprise formations of Permian and Upper Coal Measure or Pennsylvania age. The Permian outcrops are probably restricted to the valley of Big Blue River from Beatrice southward. The rocks are mainly magnesian limestones of light color, with interbedded shales. They are extensively exposed south of Beatrice, at Rockford, Bluesprings, Wymore, and Holmesville. The other Carboniferous members appear to comprise the Cottonwood and Wabaunsee formations of the Kansas geologists. They consist of limestones, shales, and sandstones, which contain thin coal beds in some localities. Professor Prosser has made a preliminary examination of the Carboniferous formations of Nebraska, and identifies as Wabaunsee the exposures about Peru, Aspinwall, Nebraska City,

[a] Darton, N. H., Preliminary report on the geology and water resources of Nebraska west of the One hundred and third meridian: Prof. Paper U. S. Geol. Survey No. 17, pp. 14-20. A colored geologic map of Nebraska, showing the surface distribution of all the formations, forms Pl. IX of the report cited. The data concerning Nebraska cement material have been obtained from Mr. Darton's report, which is in part cited verbatim.

Auburn, Tecumseh, Dunbar, Nehawka, Weeping Water, and along Platte River near Louisville. The Cottonwood limestone, a massive bed full of *Fusulina*, was recognized west of Auburn about Glenrock and Johnson, and the same beds extend over the higher lands of western Richardson and Pawnee counties.[a] In the deep borings which have been made at various points in the southeastern corner of the State it has been found that the Carboniferous formations have a total thickness of about 1,200 feet, of which about 200 feet are Permian.

NIOBRARA AND BENTON FORMATIONS.

Underlying the Pierre clay is a series of shales and chalky limestones. The shales are known as the Benton formations and the limestone, as the Niobrara formation. They have a thickness of about 450 feet to the east, but thicken to the west. At the base there are about 200 feet of dark shales, overlain by slabby limestones of the Greenhorn formation containing *Inoceramus*, which are followed by a series of shales with few thin sandy layers, and at the top the Niobrara formation with its chalky deposits, characterized by thin, hard beds filled with *Ostrea congesta*. The formations cross the eastern part of the State, and underlie all of the area west of the vicinity of the ninety-seventh meridian, but are so deeply buried under drift and loess that outcrops are rarely visible. The most extensive exposures are along the Missouri River, extending from near the ninety-seventh to the ninety-ninth meridian, and along the Republican Valley from Alma to near Superior. The formations are exposed at intervals across the eastern portion of the State in each of the larger valleys and some of the branches. The more notable of these small outcrops are at Genoa, north of Germantown, near Crete, at Pleasanthill, and in Beaver Creek north of Dorchester. There is an exposure of dark shales under some ledges of Greenhorn limestone in Big Blue River at Milford, which are Benton. Benton and Niobrara beds also occur in a prominent anticline along White River in the vicinity of Beaver and Alkali creeks, in the northwestern portion of the State.

PIERRE CLAY.

All of Nebraska west of the ninety-eighth meridian is underlain by the Pierre clay. Its surface outcrops are in the lower portion of the Niobrara Valley, the Republican Valley, and the extreme northwest corner of the State, but it is probable that careful search will reveal outcrops in the valley of the Platte River in the vicinity of the ninety-sixth meridian. The formation is a thick mass of dark-gray or bluish clay or soft shale. Its thickness is probably at least 2,000 feet in the west-central portion of the State.

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[a] Jour. Geol., vol. 5, 1897, pp. 1-16.

NEVADA.

Nevada contains numerous areas of low-magnesia limestone, mostly of Carboniferous age, though pure limestones of later date also occur within the State. The principal outcrops of the Carboniferous limestones are in the eastern third of the State. Much of this material would be suitable for use in a Portland cement plant, if commercial conditions should justify the erection of such a plant. At present, with a scanty population, expensive fuel, and practically no local demand for cement, it is evident that such an industry could hardly be even moderately successful.

The following analyses of limestones from different localities in Nevada will serve to indicate the character of the limestones above referred to. It will be noted that many of them, while low in magnesia, are very siliceous.

Analyses of Nevada limestones.

	1	2	3	4	5	6	7	8	9	10
Silica (SiO_2)	31.51	20.99	1.35	0.04	4.53	1.61	7.38	31.12	12.07	22.00
Alumina (Al_2O_3)	3.79	1.09	.36	.05	.19	.26	.80	.43	1.28	5.14
Iron oxide (Fe_2O_3)				n.d.			.68		.57	2.04
Lime (CaO)	34.33	39.77	54.51	55.16	51.69	52.16	48.52	35.82	45.29	37.22
Magnesia (MgO)	1.12	2.80	.27	.76	1.04	2.47	2.46	.86	1.86	1.89
Alkalis (K_2O, Na_2O)	n.d.	tr.	tr.	.61	n.d.	n.d.	n.d.	n.d.	.90	n.d.
Carbon dioxide (CO_2)	27.77	32.80	43.13	43.54	41.75	43.70	40.84	29.16	36.23	28.53
Water	1.25	1.06	.11	n.d.	n.d.	n.d.	n.d.	2.10	2.65	3.32

1. Limestone from Lower Coal Measures, Grand Peak, Nev.
2. Limestone from Upper Coal Measures, Tenabo Peak.
3. Carboniferous, Fremonts Pass.
4. Triassic, between Pyramid Lake and Winnemucca Lake.
5. Triassic, Star Canyon.
6. Triassic, Cottonwood Canyon.
7. Miocene, Fossil Hill.
8. Miocene, Valley Wells.
9. Pliocene, Pine Valley.
10. Recent, shore of Pyramid Lake.

Analyst of Nos. 1-9, B. E. Brewster, Fortieth Parallel Survey, vol. 2.
Analyst of No. 10, T. M. Chatard, Bull. 168, U. S. G. S., p. 776.

PORTLAND-CEMENT RESOURCES OF NEW JERSEY.

PORTLAND-CEMENT MATERIALS.[a]

New Jersey at present ranks second in the production of Portland cement in the United States. This high rank is due to the amount manufactured by relatively few, but very large, cement plants. All of these plants, which are located in Warren County, employ the same

[a] A very detailed description of the limestones of New Jersey available for use in Portland-cement manufacture, with maps showing their distribution and outcrops, is given in the Annual Report of the State Geologist of New Jersey for 1900, pp. 1-101. This valuable report has been freely used in the preparation of the present sketch, and many of the details regarding the formations are stated in Doctor Kümmel's words.

materials that are used in the Lehigh district of Pennsylvania, i. e., an argillaceous limestone mixed with a relatively small amount of pure limestone.

Limestones suitable for Portland-cement manufacture occur in several different geologic formations. The deposits of argillaceous limestone of Trenton age are, however, the principal source of cement material, and in view of the great extent of these deposits, it seems probable that the bulk of the New Jersey production will always be derived from these Trenton rocks. For this reason the distribution and character of the Trenton argillaceous limestones (Lehigh cement rock) of Warren and Sussex counties will be discussed in considerable detail, while the other limestones of the State occurring in the upper Delaware Valley will be described somewhat briefly on a later page (p. 240). The shell-marl deposits are also described (p. 242).

LIMESTONES OF WARREN AND SUSSEX COUNTIES.

In order that the descriptions of the character, thickness, etc., of the Trenton limestone may be readily comprehended, it will be necessary to pay some attention to the rock formations above and below it. That part of the geologic column in the New Jersey cement district which is now under discussion contains four formations. These are, reckoning from the top downward:

1. Hudson shales.
2. Trenton limestone.
3. Kittatinny limestone.
4. Hardyston quartzite.

In order to understand the respective bearing of these three formations on the cement industry, it is well to recollect that the Trenton limestone formation furnishes all the "cement rock," while the pure limestone used for mixing with the cement rock is obtained partly from the Kittatinny limestone, though the Kittatinny beds are in general highly magnesian. The Hudson shales, though not at present used in the cement industry, could well be utilized for mixing with a "cement rock" that is too high in lime. As these three formations, therefore, are worthy of consideration in connection with the cement industry, they will be described separately in some detail. The Hardyston quartzite, while not directly connected with the cement industry, is an easily recognized formation whose outcrops usually limit the Kittatinny limestone belt on the south.

HARDYSTON QUARTZITE.[a]

At the base of the great limestone formation of the Kittatinny Valley a thin bed of sandstone or quartzite is found at many points.

[a] These descriptions of the formations are quoted almost verbatim from Doctor Kümmel's report, previously referred to.

It rests upon the crystalline rocks (gneisses, schists, etc.) which form the highlands, and is the earliest of the Paleozoic formations in this region. It varies considerably in composition and in thickness. In many places it is apparently only a coarse and more or less friable sandstone, the grains of which are cemented together by lime carbonate. When fresh its color is steel-blue, but the weathered portions are always a rusty brown from the staining of iron oxide. It usually, but not always, contains considerable feldspar. In other localities it is a true quartzite, made up of sand grains with siliceous cement. Elsewhere it is a conglomerate, usually of pebbles less than an inch in diameter, but sometimes containing well-rounded fragments 2 to 4 inches in size. The pebbles are chiefly of quartz, feldspar, granite, gneiss, and slate; and bits of mica also occur. Locally the conglomerate, where it approaches the gneiss, can be distinguished only with great difficulty from it by the naked eye. It is simply a decomposed gneiss or granite, slightly reassorted and cemented to form a conglomerate.

The thickness of the quartzite varies from a few feet or less to 200 feet or more. Where the rock is thick it is a conglomerate or a coarse pebbly quartzite. Where thinner it is usually a calcareous sandstone, grading upward into a limestone, and, perhaps, having near its base one or more thin layers of siliceous sandstone or even quartzite. The crystalline foundation on which the quartzite rests was somewhat irregular, so that the formation varied greatly in thickness and lithological character, and at the time of its deposition the land lay not far to the southeast of the present outcrop of this rock.

KITTATINNY MAGNESIAN LIMESTONE.

The quartzite grades upward into a highly magnesian limestone formation of great thickness. This is commonly called the "blue" limestone to distinguish it from the white, coarsely crystalline limestone found near Franklin Furnace and other localties in Sussex and northern Warren. Its color, however, is not always blue. It is frequently gray, sometimes almost white, also drab, or even black. It is fine and even grained. Many of the beds are minutely crystalline, so that the freshly broken surface has a close resemblance to fine-grained lump sugar. But it is never coarsely crystalline or marble-like.

This formation occurs in beds which vary greatly in thickness and regularity. In part it is made up of thin leaf-like layers of limestone alternating with thin sheets of greenish shale. In other beds the layers of limestone are an inch or more in thickness, and are separated by thinner partings of shale or sandstone. Locally the limestone layers are apparently discontinuous, and the shale or sandy layers not only separate but inclose the more limy messes. In great part, however, this formation is composed of regular beds, one, two, three, or

even more feet in thickness. Locally they are so massive and the formation is so regularly jointed that it is extremely difficult to determine the true position of the beds. Some layers, also, are oolitic, i. e., made up of minute round particles somewhat closely resembling fish roe. The oolitic layers are apparently confined to the lower portion of the formation.

A marked feature of this formation is the chert, or black flint, which occurs either as seams, sometimes 8 or 10 inches thick, or as separate masses. The chert layers are usually, but not always, parallel to the bedding planes. Owing to the large percentage of magnesia nearly everywhere present in this limestone it is of no value in the manufacture of Portland cement. In some localities, however, it has been extensively burned for lime.

Its thickness is apparently between 2,500 and 3,000 feet, but accurate measurements can not be obtained. More than 99 per cent of the limestone of Sussex, Warren, and Hunterdon counties belongs to this formation.

Analyses of magnesian Kittatinny limestones, New Jersey.[a]

	Lime (CaO).	Magnesia (MgO).	Carbonic acid (CO_2).	Alumina and iron oxide (Al_2O_3, Fe_2O_3).	Silica and insoluble material (SiO_2).
1	27.6	17.9	41.9	1.7	9.9
2	30.4	19.1	44.9	.8	3.6
3	30.0	19.4	44.9	2.7	2.3
4	29.3	19.5	44.6	2.2	4.0
5	29.1	19.3	43.6	1.2	6.4
6	27.9	17.7	41.4	.9	11.2
7	30.3	16.2	41.6	.6	9.8
8	23.6	16.2	36.04	6.0	15.7
9	26.5	18.4	40.4	5.43	7.0
10	29.4	20.3	45.7	.6	1.8
11	28.6	18.1	34.5	.9	9.3
12	29.0	20.2	44.9	.9	4.8
13	28.5	17.3	41.5	1.7	9.9
14	29.6	20.0	45.4	1.4	2.3
15	29.6	19.2	46.2	1.4	2.9
16	29.2	18.8	43.6	2.4	3.6
17	30.1	20.1	44.4	.8	3.5
18	30.8	19.2	45.4	1.1	3.6
19	29.8	19.9	45.4	1.0	3.4
20	28.2	17.7	41.7	.9	10.8

[a] Analyses 1-7, 10-21, 27-33 are from the Geology of New Jersey, 1868. Analyses 8 and 9 are from the Annual Report of the State Geologist for 1873; Nos. 22-25 from the report for 1878; No. 26 from the report for 1876, and Nos. 34-39 were made by Mr. Myers, of Rutgers College, for the Annual Report for 1900, New Jersey State Geologist. The entire table is taken from page 33 of the last-named report.

Analyses of magnesian Kittatinny limestones, New Jersey—Continued.

	Lime (CaO).	Magnesia (MgO).	Carbonic acid (CO_2).	Alumina and iron oxide (Al_2O_3, Fe_2O_3).	Silica and insoluble material (SiO_2).
21	29.4	17.8	42.8	0.8	8.8
22	29.9	Undet.	Undet.	Undet.	2.0
23	29.6	Undet.	Undet.	Undet.	2.8
24	25.7	Undet.	Undet.	Undet.	1.9
25	26.6	Undet.	Undet.	Undet.	4.1
26	28.2	20.2	44.3	1.3	5.5
27	27.7	17.4	43.0	1.9	7.2
28	26.4	15.1	45.0	3.7	9.8
29	27.3	14.6	44.8	6.5	4.9
30	32.4	15.5	42.5	8.4	2.0
31	26.3	17.4	41.1	5.3	8.0
32	30.3	18.3	44.1	1.6	4.1
33	31.6	18.3	45.2	3.0	1.6
34	28.22	19.07	....	1.90	8.13
35	28.61	20.52	44.88	1.10	5.90
36	29.62	20.63	....	1.06	4.92
37	30.13	21.71	....	1.40	1.95
38	28.27	15.30	38.88	.98	16.9
39	29.8	19.93	....	.84	7.23

1. Chandlers Island, Vernon Township, Sussex County.
2. Near William Richey's, Vernon Township, Sussex County.
3. Near David Perry's, Wantage Township, Sussex County.
4. Near Samuel Vanderhoof's, Wantage Township, Sussex County.
5. Near William Dewitt's, Wantage Township, Sussex County.
6, 7. On property of Edward Lewis, Wantage Township, Sussex County.
8, 9. Railroad cut one-fourth mile northwest of Hamburg station, on the New York, Susquehanna and Western Railroad.
10, 11, 12. Moore & Cutler's quarry, Newton, Sussex County.
13. Near Sparta, Sussex County.
14. East of Van Kirk's tavern, Columbia, Warren County.
15. Quarry in the town of Belvidere.
16. Robert Shimer's quarry, Springtown, Warren County.
17. Henry R. Kennedy's quarry, Springtown, Warren County.
18. Charles Twinning's quarry, south of Phillipsburg.
19. James Riddle's quarry, New Hampton, Warren County.
20. Railroad cut east bank of creek, Changewater, Warren County.
21. Mahlon Fox's quarry, 1 mile southwest of Asbury, Warren County.
22-25. Quarries at Pennwell (Penville), Musconetcong Valley.
26. Quarry at Oxford furnace.
27. S. H. Leigh's quarry, near Hoffman's mill, south of Lebanon, Hunterdon County.
28. Near Clinton, Hunterdon County.
29. T. Mulligan & Brothers' quarry, Clinton.
30. Pottersville, Somerset County.
31. Henry Hilliard's quarry, north of Peapack.
32. Moses Craig's quarry, Peapack.
33. Peapack.
34. O'Donnell & McManniman's quarry, Newton. Middle of a thick, dense, even-textured, blue limestone 3 feet from the top.
35. The same. Middle of a massive blue layer 8 feet thick, 7 feet below specimen 34.
36. The same. Layer 3 inches thick, 4 feet below specimen 35. Rock a pale blue, with faint streaks of pale yellow.
37. The same. Granular layer 8 feet below No. 36. Rock dark colored and semicrystalline.
38. Gano's quarry, Annandale.
39. Mulligan Brothers' quarry, Clinton.

TRENTON LIMESTONE.

Above the magnesian Kittatinny limestone and resting on it is a dark-blue or black fossiliferous limestone. In the early reports of the New Jersey geological survey it is called the "fossiliferous" limestone, in distinction from the Magnesian or Kittatinny limestone, in which fossils had not been found at that time. In age it is to be correlated with the basal portion of the Trenton series of New York.

A continuous section of this formation is nowhere exposed, but in general the succession of beds is about as follows:

Section of black fossiliferous limestone of New Jersey.

	Feet.
(*a*) Black calcareous shales or earthy limestone, gradually becoming less calcareous and more siliceous or clayey and grading into the overlying slate. Thickness is apparently variable	40
(*b*) A rough, irregularly bedded, dark-blue limestone, breaking into knotty slabs	43
(*c*) Probably calcareous shale, usually not exposed	32
(*d*) Blue-black, earthy limestone, rather evenly bedded, weathering to a light blue gray	32

In Sussex County the total thickness is uniformly about 135 to 150 feet, except where faults have probably repeated some layers. The formation, however, thickens to the southwest, being probably at least 300 feet at the Delaware, and possibly even more than this in the Lehigh Valley region, Pennsylvania. The increase in thickness is apparently in the upper calcareous shaly beds.

The Trenton rests upon the eroded surface of the Kittatinny limestone, so that there is here a break in the geologic record. At many places the lowest Trenton beds form a conglomerate composed solely of pebbles and bowlders of the underlying magnesian limestone and chert. Elsewhere pebbles of magnesian limestone and chert are included in a matrix of pure limestone, which is sometimes fossiliferous.

Many analyses have been made of specimens both of the limestone and of the calcareous shales of the Trenton formation. The more massive beds contain from 85 to 95 per cent of carbonate of lime and only small amounts of magnesia. Some of the more shaly layers contain 65 to 75 per cent of carbonate of lime, with sufficient alumina and silica to make a good cement rock. It is this rock which is used with such success in manufacturing Portland cement near Phillipsburg, Warren County, N. J., and in Berks, Lehigh, and Northampton counties, Pa. The purer limestone beds can be used to mix with the "cement rock" in order to raise the percentage of lime to the necessary figure.

Analyses of Trenton limestone, New Jersey.[a]

	Silica (SiO_2).	Alumina (Al_2O_3), iron oxide (Fe_2O_3).	Lime (CaO).	Magnesia (MgO).	Carbon dioxide (CO_2).
1	17.71	7.91	41.79	0.38	33.25
2	14.59	6.86	40.30	.67	32.50
3	10.71	5.98	40.00	.65	32.15
4	10.26	7.19	44.72	1.40	36.68
5	20.58	5.44	39.84	.63	32.00
6	8.42	2.30	44.64	.36	34.47
7	18.60	5.80	38.76	.66	31.20
8	2.27	.46	54.98	.84	....
9	11.86	1.09	48.36	.56	....
10	43.38	4.37	24.89	3.74	....
11	10.49	.75	49.10	1.13	....
12	1.8	.2	54.7	....	43.00
13	15.8	1.6	43.2	2.2	31.4
14	.97	.86	55.70	.45	....
15	8.10	2.38	48.04	2.84	....
16	4.30	1.23	52.58	.65	....
17	2.62	.38	54.00	1.00	....
18	14.27	1.48	46.66	.31	....
19	13.00	1.03	47.80	1.35	....
20	2.54	1.14	53.64	.81	42.72
21	10.67	1.49	49.03	.70	....
22	26.51	1.63	43.09	.78	....
23	9.53	1.81	49.11	.65	....
24	13.41	1.46	49.13	.34	....
25	13.52	.61	39.12	8.21	....
26	17.23	2.44	41.12	3.78	....
27	8.48	1.04	37.95	11.68	....
28	24.91	2.37	30.46	9.82	....
29	5.8	4.7	49.00	.9	....
30	4.33	1.1	52.76	.84	....
31	3.19	1.27	52.85	.76	....
32	2.87	1.82	54.04	.81	....
33	13.05	1.42	47.95	.57	....
34	11.96	1.60	46.88	.40	....
35	5.50	1.94	50.16	1.67	....
36	14.85	1.41	47.55	.65	....
37	1.70	.81	54.26	1.09	....
38	6.6	.80	49.04	1.00	40.1
39	7.83	1.19	50.65	.55	40.41

[a] From Ann. Rep. for 1900, N. J. State Geologist.

Analyses of Trenton limestone, New Jersey—Continued.

	Silica (SiO_2).	Alumina (Al_2O_3), iron oxide (Fe_2O_3).	Lime (CaO).	Magnesia (MgO).	Carbon dioxide (CO_2).
40	29.78	8.29	30.10	2.13	....
41	2.64	.82	53.88	.72	....
42	27.08	8.76	31.00	1.83	....
43	11.72	1.00	47.37	2.06	....
44	5.46	1.83	49.38	2.26	....
45	22.72	8.15	35.78	1.86	....

1-5. Murphy farm, near Carpentersville.
6-7. One mile southwest of Pattenburg.
8. Near Branchville.
9. Near Myrtle Grove.
10. Near Swartswood station.
11. Swartswood village.
12-13. Northwest of Stillwater.
14. Near Jacksonburg.
15. Hainesburg.
16. Columbia.
17-20. Near Beaver Run.
21-22. Near Monroe Corners.
23-25. Near Lafayette.
26-30. Near Newton.
31-33. Near Drakes Pond.
34. Three miles southwest of Newton.
35-36. Near Huntsburg (Hunt's mills).
37-40. Springdale.
41. Swayze's mills.
42. Near Hope.
43-44. Sarepta.
45. Near Belvidere.

The Trenton limestone can be readily distinguished from the magnesian Kittatinny limestone by the following points: (1) The Trenton is usually fossiliferous. Some surfaces are covered entirely with imprints of shells. Beds otherwise unfossiliferous usually contain crinoid stems, which are best seen on weathered surfaces as small disks, often with a hole in the center. The fossils of the Kittatinny limestone are so few and so obscure that only an expert can detect them, so for practical purposes the formation can be considered unfossiliferous. (2) The dark blue or black color of the Trenton weathers to a light gray-blue, entirely unlike most of the Kittatinny beds. So, too, the rough, knotty character of the bedding and of the weathered slabs is characteristic of the Trenton limestone. (3) A drop of hydrochloric acid will cause the Trenton limestone to effervesce vigorously, whereas the cold acid dropped on the Magnesian limestone acts weakly or not at all. (4) The Trenton may usually be recognized by its position. It lies on top of the Kittatinny limestone and beneath the slate, which is the next higher formation, so that its outcrop forms a narrow strip between the wider belts of these rocks. It is not found, however, in this position where faulting has brought the slate against the Magnesian limestone, and it is sometimes faulted into the midst of the

Magnesian limestone areas, as will be explained below. (5) The Magnesian limestone contains frequent masses of black flint or chert. This is never found in the Trenton limestone in New Jersey, except as water-worn pebbles in the basal conglomerate.

HUDSON SHALES.

The shaly limestones of the Trenton become more clayey and less limy, and gradually pass into a series of shales, slates, and sandstones. This formation has usually been known as the Hudson shales. The shales are commonly black or dark gray, although green and red beds occasionally occur. Much of this rock has a marked tendency to split into thin sheets. This cleavage is not along the bedding planes or layers in which the slate was deposited, but cuts across them at various angles. It is in virtue of this tendency to split smoothly and regularly into thin layers that some zones of this formation yield excellent roofing slates; and in some localities, as at Newton, N. J., and Slatington, Pa., they are largely quarried for this purpose.

There is considerable difference in the chemical constitution of various members of this formation, owing to the variations from shale and slate to sandstone.

Analyses of Hudson shales and slates, New Jersey.

	1	2	3	4	5	6
Silica (SiO_2)	56.60	68.00	[a]77.53	[a]76.22	[a]79.36	[a]81.17
Alumina (Al_2O_3)	21.00	14.40	10.10	13.05	10.73	9.80
Iron oxide (Fe_2O_3)	5.65	5.40				
Lime (CaO)	3.42	2.68	3.56	2.67	2.07	1.13
Magnesia (MgO)	2.30	1.51	4.28	.93	2.57	2.48
Alkalies (KO_2, Na_2O)	.50	.11				
Sulphur (S)	.57					
Carbon dioxide (CO_2)	2.20	2.30				
Water	3.00	2.70				

[a] Insoluble.

1. Delaware Water Gap. Geology New Jersey, 1868, p. 136.
2. One mile northwest of Coleville. Ibid.
3. Near Annandale. Ann. Rept. New Jersey State Geol. for 1900, p. 52.
4. Near Lafayette. Ibid., p. 74.
5. Newton slate quarry. Ibid., p. 77.
6. Near Drakes Pond. Ibid., p. 78.

GEOLOGIC STRUCTURE.

The general relations of these formations—the Hardyston quartzite, the Kittatinny limestone, the Trenton limestone, and the Hudson slate—are usually very simple and easily understood. They have

been bent into great folds, which originally formed a succession of arches and troughs. During the enormously long period which has elapsed since the folding occurred, hundreds, perhaps thousands, of feet of strata have been worn off from the arches, so that beds which were once deep below the surface are now exposed to view. The axes of these folds extend in a northeast-southwest direction, so that the formations lie in long and comparatively narrow belts that extend in the same direction. Along the central line of an upfold of the strata or anticline the older rock is exposed. The beds slant or dip away from the axis, and younger and higher beds are found toward the flanks. The Kittatinny limestone, being older than the Trenton and Hudson, occurs along the central line of the anticlines.

The reverse relations are true where the strata are downfolded, i. e., at the synclines. Here the younger beds are found along the medial line, toward which the strata dip, and the older beds are found on the flanks.

The simple structure of anticlinal and synclinal folds is often complicated by faults or fractures, along which the strata have moved past one another. The fault planes may be inclined at various angles, and the motion may have been in any direction along them. As a result of faulting a given bed may not appear at the surface, or it may be repeated and form a double line of outcrops. Consequently the Trenton limestone does not occur everywhere between the outcrops of slate and Kittatinny limestone where it is expected, and it sometimes does occur apparently in the midst of the older limestone formation where it is not expected. Again for long intervals the rock may be buried beneath thick accumulations of glacial drift, which conceal its outcrop, but in these cases it can always be found by digging.

LIMESTONES OF UPPER DELAWARE VALLEY.

Limestones and calcareous shales of various kinds are found along Wallpack Ridge, from Tristates to Wallpack Bend, on Delaware River. With the exception of that part of the ridge near Tristates all this area is so far removed from any railroad that for lack of transportation facilities any deposits of cement rock and limestone within it must remain undeveloped for many years. For this reason these limestones were not studied with the same care as those of the Kittatinny Valley.

Doctor Cook published in 1868 analyses of specimens from various horizons, which indicate that many of the beds have a high percentage of carbonate of lime, and are practically free from magnesia. Finely ground and mixed with clay in the right proportion they would make good Portland cement, or the rock could be used to raise the percentage of lime in a cement rock deficient in it. These formations were described by Mr. Weller in the annual report for 1899, pages 1–46.

A specimen of the Bossardville limestone (Cook's ribbon limestone) from Richard Stoll's farm near Wallpack Center had the following composition:

Analysis of Bossardville limestone from near Wallpack Center.

Silica (SiO_2)	12.80
Alumina and iron oxide (Al_2O_3 and Fe_2O_3)	2.10
Lime (CaO)	44.85
Magnesia (MgO)	2.18
Carbon dioxide (CO_2)	37.68

Outcrops of the Bossardville limestone are numerous from Flatbrookville to Peters Valley, along the eastern foot of the ridge. At the Nearpass quarry, near Tristates, it is exposed just above the base of the section there shown, and has a thickness of 12 feet 4 inches.

Specimens from other limestone formations exposed in Sandford Nearpass's quarry, near Tristates, were analyzed by Cook, with the following results:

Analyses of limestones from Nearpass quarry, near Tristates, N. J.

	1	2	3	4
Silica (SiO_2)	8.50	4.00	22.80	4.10
Alumina (Al_2O_3)	16.90	1.10	8.94	.90
Oxide of iron (Fe_2O_3)			2.57	
Lime (CaO)	39.87	52.52	20.44	52.92
Magnesia (MgO)	1.42	.33	12.08	....
Carbon dioxide (CO_2)	33.31	41.80	31.06	41.58

No. 1 is Cook's "firestone," a part of the Decker Ferry formation. No. 2 is Cook's "old-quarry stone," the identification of which is somewhat indefinite, but it is probably the top of the Rondout waterlime formation. No. 3, the so-called "pethstone," is No. 7 of the Waterlime formation (p. 20, Annual Report for 1899). No. 4, the "quarry stone," is the Tentaculite limestone. Another specimen of the Tentaculite limestone had 51.5 per cent of lime and 5.5 per cent of silica and quartz.

The Nearpass quarry is not so far removed from the railroad at Port Jervis but that some of these beds may be profitably utilized. Analyses 2 and 4 above show that the "old-quarry stone" and the "quarry stone" are high-grade limestones. Analysis of the shaly layers in the quarry may show a rock with the right proportions of alumina and silica. In Mr. Weller's paper, in the report for 1899, some of the important exposures of these formations are noted.

Doctor Cook also gives the following analyses of specimens, the exact geologic horizon of which can not be determined from the record:

Analyses of Silurian limestones.

	1	2	3
Silica (SiO_2)	9.80	8.70	10.80
Alumina and iron oxide (Al_2O_3 and Fe_2O_3)	2.10	1.50	2.60
Lime (CaO)	48.88	49.67	45.19
Magnesia (MgO)	.35	.69	.80
Carbon dioxide (CO_2)	38.90	40.00	36.75

1. Limestone from John Schooley's farm, near Peters Valley.
2. Limestone from farm of Joshua Cole, Montague.
3. Limestone from farm of Calvin Decker, Wallpeck Ridge.

WHITE MARL DEPOSITS.

In addition to the limestones described in the previous part of this report, there are in Sussex and Warren counties shell-marl deposits, often of considerable extent, some of which may be sufficiently pure to be used for Portland cement in combination with clay. No recent study of these deposits has been made, but the following data, from the earlier reports of the New Jersey Geological Survey, particularly from the annual report of 1877, may be of value in this connection. These partial analyses were published in 1877:

Analyses of New Jersey marls.

	Calcium carbonate ($CaCO_3$).	Magnesium carbonate ($MgCO_3$).	Sand and clay.	Water, vegetable material, etc.	Description.	Location.
1...	98.33	....	0.90	0.67	White, pulverulent; no vegetable matter.	Andover, Sussex County.
2...	88.86	....	9.96	2.16	Precipitate from water.	Peters Valley, Sussex County.
3...	97.73	....	.60	1.59	White, dense, fine	Shiloh, Warren County.
4...	95.34	2.18	.98	1.50	Surface marl, white, solid, fine.	Do.
5...	96.32	1.57	1.16	.96	Drab white, fine and with shells.	Hunt's mill, Sussex County.
6...	92.25	2.98	1.56	3.21	White, pure, some grass roots.	Marksboro, Warren County.
7...	89.87	2.29	.97	6.87	Ash colored, many shells, light.	Hope, Warren County.
8...	96.54	1.47	2.05	0.00	White, very fine, medium density.	Newton, Sussex County.
9...	84.52	1.76	8.46	5.26	Surface marl..........	Do.

Analyses of New Jersey marls—Continued.

	Calcium carbonate ($CaCO_3$).	Magnesium carbonate ($MgCO_3$).	Sand and clay.	Water, vegetable material, etc.	Description.	Location.
10..	90.18	0.00	9.75	....	White, very dense, thick shells.	Lincoln, Warren County.
11..	99.04	0.00	.55	.41	White, very light, pure.	Do.
12..	68.73	0.00	23.99	7.28	Dark-colored shells and vegetable matter.	Montague, Sussex County.
13..	94.75	0.00	.71	4.54	White, very light, pure.	Monroe Corners, Sussex County.
14..	64.20	0.00	16.21	16.59	White shells and clay..	Centerville, Sussex County.

PORTLAND-CEMENT INDUSTRY IN NEW JERSEY.

Three Portland cement plants are at present in operation in New Jersey, all of them in Warren County, and all using the Trenton cement rock as their principal raw material. In raw materials and general practice these plants agree with the others of the Lehigh district, described on page 284, to which reference should be made for a general discussion of the subject. The following data on the history and production of the three New Jersey plants are taken from a recent report of the New Jersey Geological Survey:

In 1891 Thomas D. Whitaker commenced the manufacture of Portland cement at Alpha, N. J., establishing what is now the Alpha Portland Cement Company. In 1895 the present operators purchased the plant, which then had a capacity of from 500 to 700 barrels a day. The rock at Alpha produced such an excellent cement that the plant was gradually increased, until in 1900 there were 10 kilns, with a capacity approximating 2,000 barrels a day. In 1901 a new mill of the same capacity was erected, the former being known as mill No. 1 and the latter as mill No. 2. In the summer of 1903, 4 more kilns were added to mill No. 2, making 14 kilns for this plant. This company is now manufacturing at Alpha about 5,000 barrels daily. Since the issue of the New Jersey Geological Survey's report of the Portland cement industry in 1900, in which the distribution of the cement rock was delineated, the company has increased its holdings from 40 acres to 200 acres. The quantity of cement manufactured by this company since its inception is, in round numbers, 6,000,000 barrels.

Production of cement at plant of Alpha Cement Company, Alpha, N. J.

	Barrels.		Barrels.
1894	100,000	1899	380,000
1895	120,000	1900	500,000
1896	215,000	1901	830,000
1897	325,000	1902	1,180,000
1898	350,000	1903	1,400,000

The method of quarrying at the Alpha quarry is to drill across the strata with steam drills and break down the rock with dynamite and load it on mine cars with a steam shovel. These cars are then hauled up an inclined railroad by a cable. Four tracks are in use at Alpha, two for each mill. In practice it is found necessary to bring up the lime content by the addition of limestone brought from Pennsylvania.

In 1894 the directorate of the Vulcanite Paving Company, of Philadelphia, in order to be assured of an adequate supply of first-quality cement to use in certain paving work, commenced the erection of a plant close to the Alpha works. The original mill had 5 rotary kilns. Later No. 2 mill, with 6 kilns, was erected. Finally an additional factory of 10 more kilns was installed, and the company has increased its holdings of cement-rock land to 250 acres.

The output to date is given as follows:

Production of cement at plant of Vulcanite Paving Company at Alpha, N. J.

	Barrels.		Barrels.
1895 (6 months)	14,000	1900	690,000
1896	60,000	1901	725,000
1897	125,000	1902	975,000
1898	218,000	1903	1,460,000
1899	513,000		

Two quarries, entirely independent of each other, are operated as pits. The rock, broken down by dynamite, is hoisted and conveyed by wire-cable tramways to the mills. Two independent cable ways are operated at each pit.

The plant of the Edison Portland Cement Company was put in operation in October, 1903. The quarries are about 2 miles from the works and are connected therewith by a standard-gage railroad. The cement rock and limestone occur in close proximity. The rock in a general way resembles that of the quarries already mentioned, although of course the excavations are not nearly so extensive as yet. A rather radical departure from quarrying methods is being inaugurated in the form of a movable roof over each quarry. This is made of corrugated iron placed on light steel frames resting on wheels which in turn run on a T-rail track. By thus covering the quarry it is intended to work it in all weathers, the roof being moved as quarrying proceeds. After the rock is blown down it is loaded into cars with steam shovels.

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HAMILTON, S. H. The cement industry [in New Jersey, 1903]. Ann. Rept. State Geologist, N. J. for 1903, pp. 112–118.

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PORTLAND-CEMENT RESOURCES OF NEW YORK.

PORTLAND-CEMENT MATERIALS.

The State of New York now ranks fourth in the production of Portland cement in the United States. The extensive series of limestones which outcrop within its borders, and its excellent local markets for cement and cement products, will probably enable it to improve its rank as a Portland-cement producer very materially within the next few years.

Of the many different limestone formations which outcrop in New York State, five are of such thickness, areal extent, and chemical composition as to be worth considering as sources of Portland-cement material. Many other limestones occur in the State, but these others may be disregarded here as being usually too thin, of improper chemical composition, or too badly located with regard to transportation routes, markets, or sources of fuel supply.

The five available limestones noted above, in their geologic order, are as follows:

5. Marls	Quaternary.
4. Tully limestone	Devonian.
3. Helderberg limestones	Silurian and Devonian.
2. Trenton limestone	Lower Silurian (Ordovician).
1. Chazy limestone	Lower Silurian (Ordovician).

All of these limestones except the first (Chazy) are at present utilized in Portland-cement manufacture in New York State.

The character and distribution of the five limestone groups above noted will now be described separately in the order in which they are listed above. Pl. X shows the actual distribution in New York State of the first four limestone groups. The Quaternary marls are widely distributed throughout the State, but occur usually in small deposits. For this reason marl deposits are not shown on this map, except in such cases as are known to be of workable size.

CHAZY LIMESTONE.

DISTRIBUTION.

The Chazy limestone is confined practically to the Lake Champlain Valley. It outcrops on the west shore of Lake Champlain, a few miles south of Crown Point village, and is also well shown in Crown Point itself. It appears again on the lake shore about 5 miles south of Westport, near Essex village, and on Willsboro Point. Its most characteristic and extensive outcrops, however, are in the eastern part of Clinton County. It is shown well on Valcour Island and on Isle la Motte, where it has been extensively quarried. On the mainland it occupies large areas north of Valcour and west of Plattsburg, where it is quarried. The largest single area is in the northeastern part of Clinton County, where it has been worked extensively for lime and building stone. This area extends almost without a break from the village of West Chazy to the lake shore and northward to the Canadian line near Rouse Point.

Local details concerning the distribution, thickness, etc., of the Chazy formation will be found in a paper by H. P. Cushing, entitled "Report on the Geology of Clinton County," in the Thirteenth Annual Report of the New York State Geologist, pages 473–490. This paper also contains geological maps of the county, showing the area covered by the limestone.

COMPOSITION.

The Chazy limestone is usually a very pure limestone, low in both magnesia and clayey matter. It is commonly bluish to grayish in color, and has a slightly crystalline appearance. Occasionally it carries notable percentages of silica, alumina, etc., but these argillaceous phases are rare. Of the analyses in the following table Nos. 1 and 2 represent the purest type of the Chazy limestone, while Nos. 3, 5, and 6 contain more or less clayey matter. Analysis No. 4 is included as representing a highly argillaceous type, occurring in the same area as Nos. 3, 5, and 6; but this particular analysis is old and of doubtful value.

Analyses of Chazy limestone, New York.

	1	2	3	4	5	6
Silica (SiO_2)	0.79	0.72	2.43	21.39	4.40	4.60
Alumina (Al_2O_3)	.14	.39	.41	3.61	7.10	4.10
Iron oxide (Fe_2O_3)	.12				3.50	1.90
Lime (CaO)	54.36	53.90	51.00	39.37	44.35	49.11
Magnesia (MgO)	.67	1.44	1.00	.52	2.00	.47
Carbon dioxide (CO_2)	43.45	43.92	n. d.	31.51	37.05	39.10

1. Chazy, Clinton County. Rept. New York State Geologist for 1897, p. 433.
2. Chazy Marble Lime Company, Clinton County. D. H. Newland, analyst. Bull. New York State Museum, No. 44, p. 755.
3. Willsboro Point, Essex County. T. G. White, analyst. Ibid., p. 782.
4–6. Willsboro Point, Essex County. E. C. Boynton, analyst. Ibid., pp. 782, 783.

counties, along the valleys of West Canada Creek and Black River. Commencing as a narrow belt near Middleville, Herkimer County, it passes northwestward, increasing to about 8 to 10 miles in width, and going through Trenton Falls, Prospect, Remsen, Boonville, Port Leyden, Lowville, and Copenhagen, at many of which points it is extensively quarried. The limestone belt here widens out greatly, being about 20 miles wide at Watertown, and extending along the St. Lawrence-Lake Ontario shore from near Clayton to near Port Ontario, a distance of over 50 miles. Within this broad area in Jefferson County the Trenton limestones are quarried at Cape Vincent, Chaumont, Clayton, Watertown, Theresa, and many other points.

COMPOSITION.

The Trenton limestone is usually a pure nonmagnesian limestone. It is dark gray to almost black in color, and is commonly highly fossiliferous.

The following analyses, which are representative of the various phases of the Trenton limestone, are arranged in geographical order along the outcrop of that limestone, beginning in Washington County, on the east, and ending in Lewis County, on the west.

Analyses of Trenton limestones, New York.

Number.	Silica (SiO_2).	Alumina (Al_2O_3).	Iron oxide (Fe_2O_3).	Lime (CaO).	Magnesia (MgO).	Carbon dioxide (CO_2).
1	0.97	0.08	0.02	54.15	0.39	42.95
2	1.38	0.58		55.26	.72	n. d.
3	.72	1.50		54.28	.80	44.00
4	.70	1.00	.70	53.09	1.04	42.05
5	2.13	1.26		53.19	Trace.	41.79
6	3.30	1.30		52.15	1.58	40.98
7	1.10	.80	.50	53.17	.75	45.08
8	6.13	.79	.61	49.55	1.17	40.22
9	1.25	3.00		52.78	....	42.97
10	3.82	1.08		52.46	....	42.64
11	5.68	2.76		52.12	....	39.44
12	6.70	3.03	.21	49.92	Trace.	39.23
13	8.45	2.72	.84	47.38	1.63	39.01
14	2.59	1.21	.61	52.00	1.04	42.00
15	3.96	1.70		51.11	1.80	42.14
16	3.09	1.15	.49	52.70	.78	42.26
17	1.44	.83		54.52	.49	43.39
18	6.50	1.67	.76	49.53	1.28	40.31

1. Keenan Lime Company, Smith's Basin, Washington County. Twentieth Ann. Rept. U. S. Geol. Survey, pt. 6, p. 427.
2. Keenan Lime Company, Smith's Basin, Washington County. Bull. New York State Mus. No. 44, p. 826.

3. Keenan Lime Company, Smith's Basin, Washington County. H. Ries, analyst. Ibid., p. 827.
4. Harris quarry, near Whitehall, Washington County. Ibid.
5. Glens Falls, Warren County. J. H. Appleton, analyst. Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 3, p. 801.
6. Glens Falls, Warren County. Mineral Industry, vol. 6, p. 97.
7. Glens Falls, Warren County. Bull. New York State Mus. No. 44, p. 825.
8. Hewitt quarry, Amsterdam, Montgomery County. Ibid., p. 749.
9. Hewitt quarry, Amsterdam, Montgomery County. J. M. Sherrerd, analyst. Twentieth Ann. Rept. U. S. Geol. Survey, pt. 6, p. 427.
10. Hewitt quarry, Amsterdam, Montgomery County. J. M. Sherrerd, analyst. Ibid., pt. 6, p. 427.
11. Hewitt quarry, Amsterdam, Montgomery County. J. M. Sherrerd, analyst. Ibid., pt. 6, p. 427.
12. Butler quarry, Ingham Mills, Herkimer County. Bull. New York State Mus. No. 44, p. 788.
13. Butler quarry, Ingham Mills, Herkimer County. Ibid.
14. Prospect, Oneida County. J. D. Irving, analyst. Ibid., p. 802.
15. Waters quarry, Lowville, Lewis County. Ibid., p. 792.
16. Roberts quarry, Collinsville, Lewis County. D. H. Newland, analyst. Ibid., p. 791.
17. Christy quarry, Leyden, Lewis County. Ibid., p. 791.
18. Snyder quarry, Port Leyden, Lewis County. D. H. Newland, analyst. Ibid., p. 791.

HELDERBERG LIMESTONES.

DISTRIBUTION.

Regarded as possible sources of Portland-cement materials, the most important series of limestone formations in New York State is that included in the Upper and Lower Helderberg groups. These two groups, each divisible into a number of well-marked formations, are separated throughout the greater part of their range by a comparatively thin bed of sandstone—the Oriskany sandstone—but for the purposes of this volume may be considered as one series of limestones. The Helderberg limestones, considered together, extend eastward from Buffalo, in Erie County, to Oriskany Falls, Oneida County. Here the belt turns about S. 30° E., nearly to South Bethlehem, Albany County. From this point the outcrops of the limestone trend almost parallel to and a little west of Hudson River, nearly to Kingston. The limestone belt then turns southeastward, passing through Ellenville and Port Jervis into Pennsylvania and New Jersey. The line of outcrop is shown in considerable detail in Pl. X.

The distribution of the Helderberg limestones is described at length in the following papers, in which maps and sections showing local details will be found:

Darton, N. H. Report on the Helderberg limestones: Thirteenth Ann. Rept. New York State Geol., pp. 197–228.

Darton, N. H. Report on the Geology of Albany County: Thirteenth Ann. Rept. New York State Geol., pp. 229–262.

Darton, N. H. Report on the Geology of Ulster County: Thirteenth Ann. Rept. New York State Geol., pp. 289–372.

COMPOSITION.

Analyses of Helderberg limestones, New York.

	Silica (SiO_2).	Alumina (Al_2O_3).	Iron oxide (Fe_2O_3).	Lime (CaO).	Magnesia (MgO).	Carbon dioxide (CO_2).
1	1.17	0.64		54.06	0.48	43.00
2	5.00	.60		51.78	.88	41.66
3	5.96	3.16	1.34	49.70	1.44	40.13
4	14.85	7.18	1.57	40.23	1.95	33.76

Analyses of Helderberg limestones, New York—Continued.

	Silica (SiO_2).	Alumina (Al_2O_3).	Iron oxide (Fe_2O_3).	Lime (CaO).	Magnesia (MgO).	Carbon dioxide (CO_2).
5	1.6	0.7		54.32	0.53	43.26
6	7.23	1.64		48.68	1.84	40.29
7	1.92	.36		52.53	.69	42.03
8	n.d.	n.d.	n.d.	35.25	8.94	37.52
9	n.d.	n.d.	n.d.	43.22	6.08	40.65
10	n.d.	n.d.	n.d.	48.82	1.48	39.99
11	5.53	1.50		50.25	1.00	40.49
12	2.48	.95		53.52	.46	42.54
13	5.56	1.55		50.47	.83	40.57
14	2.57	1.55		52.69	.84	42.33
15	5.66	2.14		50.25	1.11	40.70
16	5.46	1.35		50.80	1.01	41.02
17	5.82	1.38		50.93	.85	40.87
18	4.45	.30		50.06	2.74	42.36
19	4.91	.48	.53	51.82	1.16	41.90
20	4.31	.97		51.05	1.65	41.90
21	1.48	n.d.	n.d.	53.62	n.d.	n.d.
22	4.12	n.d.	n.d.	52.46	n.d.	n.d.
23	9.05	6.66	.99	44.72	1.98	37.33
24	5.12	1.45	.74	48.34	2.93	41.22
25	11.16	3.35	1.15	44.27	3.17	38.27
26	1.27	.73		54.51	.66	43.46
27	1.84	.63	1.82	51.40	2.23	41.19
28	1.89	1.01	.55	51.35	1.67	42.19
29	2.75	1.50	1.60	53.10	n.d.	n.d.
30	7.10	2.50	1.65	45.22	Trace.	39.10
31	3.87	1.07	1.34	54.11	Trace.	40.60

1. Fogelsonger quarry, Williamsville, Erie County. H. Carlson, analyst. Twentieth Ann. Rept. U. S. Geol. Survey, pt. 6, p. 427.
2. Howells quarry, Leroy, Genesee County. Bull. New York State Mus., No. 44, p. 784.
3. Strobel quarry, Leroy, Genesee County. Ibid.
4. Babcock quarry, Waterloo, Seneca County. Ibid., p. 819.
5. Alvord quarry, Jamesville, Onondaga County. F. E. Engelhardt, analyst. Ibid., p. 806.

6–12. Clinton, Oneida County. A. H. Chester, analyst. Ibid., p. 802.

13–17. Oriskany Falls, Oneida County. A. H. Chester, analyst. Ibid.

18. Putnam quarry, Oriskany Falls, Oneida County. Ibid., p. 803.
19. Manning quarry, Columbia, Herkimer County. Ibid., p. 788.
20. Cobleskill Quarry Company, Cobleskill, Schoharie County. C. F. McKenna, analyst. Twentieth Ann. Rept. U. S. Geol. Survey, pt. 6, p. 427.

21, 22. Howes Cave, Schoharie County. C. A. Schaeffer, analyst.

23–25. Callanan quarry, South Bethlehem, Albany County. Bull. New York State Mus., No. 44, p. 771.

26. Howes Cave, Schoharie County. C. A. Schaeffer, analyst. Twentieth Ann. Rept. U. S. Geol. Survey, pt. 6, p. 427.

27, 28. Hudson, Columbia County. Ibid., p. 427.

29. Holdredge quarry, Catskill, Greene County. H. Ries, analyst. Bull. New York State Mus., No. 44, p. 787.
30. Turner quarry, Wilbur, Ulster County. Ibid., p. 822.
31. Rondout, Ulster County. Ibid.

TULLY LIMESTONE.

DISTRIBUTION.

The thinness of the Tully limestone would probably allow it to be disregarded as a Portland-cement material if it were not for its advantageous distribution. It occurs only in central New York, and occupies a greater area than any other limestone in that part of the State. Its line of outcrop, moreover, crosses all the Finger lakes, on the shores of most of which the limestone is well exposed, and the belt is crossed by numerous railroad lines leading to the coal regions of Pennsylvania. With these advantages of position, even a relatively thin limestone bed is worth considering, and one Portland-cement plant that uses the Tully limestone is already in operation.

The most western known exposure of the Tully limestone is near Reed Corners, Ontario County. From this point it runs southeastward through or near Gorham, Stanley, Hall Corners, and Dresden, disappearing below the waters of Seneca Lake opposite the village of Starkey. It reappears on the east shore of the lake about 5 miles south of Willard, and is exposed almost continuously along the lake shore as far north as Willard. Here it turns eastward through Hayt Corners, then southeastward near Sheldrake to the Cayuga Lake shore east of Covert, and thence southward along the west shore through Trumansburg to Glenwood. Its most available outcrops are, however, on the east shore of Cayuga Lake, which it follows closely from Portland Point north to opposite Kings Ferry. Turning northeastward the limestone outcrop leaves the lake and passes through Poplar Ridge, Sherwood, and Scipio. From this point to its most eastern known outcrop, which is near Smyrna, Chenango County, the outcrop of the Tully limestone is too irregular for ready description, as can be seen from the map, Pl. X, opposite page 246. It is sufficient here to indicate its course by saying that the principal villages and stations on or near the outcrop are, in order eastward, Cascade, Locke, Moravia, Miles, Glenhaven, Scott, Spofford, Borodino, Otisco Valley, Tully, Truxton, Cuyler, Deruyter, Georgetown, and Smyrna.

COMPOSITION.

The Tully limestone is low in magnesia, rarely carrying over 1½ per cent of magnesium carbonate. It commonly carries a rather large percentage of silica, alumina, and iron oxide, at times approximating in composition the Lehigh cement rock. The analyses given on page 252 are fairly representative of its range in composition.

The limestone is immediately underlain by a series of shales which, as shown by the experience of the Portland-cement plant near Ithaca, are well adapted to mixing with the limestone.

Analyses of Tully limestone, New York.

	1	2	3	4	5	6
Silica (SiO_2)	9.72	6.30	7.88	5.7	4.0	15.0
Alumnia (Al_2O_3)	4.20	3.35	4.01	2.1	26.0	23.0
Iron oxide (Fe_2O_3)	.48					
Lime (CaO)	47.11	50.25	48.10	49.56	33.6	30.0
Magnesia (MgO)	.66	.22	.53	.67	2.6	1.3
Carbon dioxide (CO_2)	n.d.	n.d.	n.d.	39.67	n.d.	n.d.

1. Top bed. Portland Point, Tompkins County. J. H. McGuire, analyst.
2. Middle bed. Portland Point, Tompkins County. I. H. McGuire, analyst.
3. Bottom bed. Portland Point, Tompkins County. J. H. McGuire, analyst.
4. Near Lansing, Tompkins County. H. Ries, analyst. Bull. New York State Mus., No. 44, p. 820.
5. Willard, Seneca County. Trans. New York Agric. Soc. for 1850, p. 611.
6. Hayt Corners, Seneca County. Ibid.

QUATERNARY MARLS.

DISTRIBUTION.

Small deposits of marl occur at many points in eastern and northern New York, filling old lake basins and now forming swampy tracts, overlain by much impure peat. So far as known, none of the deposits in this part of the State are of workable size.

In western and central New York, however, large marl deposits have been found at many points. They are, or have been, utilized in the manufacture of Portland cement at Montezuma, Cayuga County; Jordan and Warners, Onondaga County; Caledonia, Genesee County; Wayland and Perkinsville, Steuben County, and Cassadaga Lake, Chautauqua County. Other large deposits, as yet undeveloped, are known [a] to occur northwest of Canastota, Oneida County; at Cortland, Cortland County; Clifton Springs, Ontario County; Clarendon, Orleans County, and Bergen, Genesee County.

COMPOSITION.

The New York marls show, on analysis, the usual variations in composition. Most of those included in the table below are actually used at Portland-cement plants.

[a] Bull. New York State Mus. No. 44, p. 767.

Analyses of Quaternary marls, New York.

No.	Silica (SiO_2).	Alumina (Al_2O_3).	Iron oxide (Fe_2O_3).	Lime (CaO).	Magnesia (MgO).	Carbon dioxide (CO_2).	Water, organic, etc.
1	0.40	0.20	0.20	53.50	0.30	n.d.	(a)
2	1.10	1.50		54.54	Trace.	n.d.	....
3	.49	.35		52.71	Trace.	n.d.	(b)
4	.50	2.00		52.70	1.09	42.61	....
5	.42	1.08		52.36	1.01	42.26	[c]0.86
6	.54	.56		54.40	2.34	42.20	
7	.14	.36		53.16	1.50	n.d.	
8	.26	.10		52.86	.18	41.73	4.64
9	.26	.21	.01	50.98	.19	40.26	7.98
10	6.22	1.70	.86	47.86	.04	42.11	(d)
11	2.10	1.93		48.78	1.10	39.53	....

[a] SO_3, 1.7 per cent. [b] $CaSO_4$, 3.48 per cent. [c] $CaSO_4$, 2.01 per cent. [d] Alkalies, 2.20 per cent.

1. Iroquois Portland Cement Company, Caledonia, Livingston County.
2. 3 miles east of Mumford, Livingston County. Bull. New York State Mus., No. 44, p. 793.
3. 1 mile west of Bergen, Genesee County. J. A. Miller, analyst. Ibid., p. 785.
4. Mumford, Monroe County. (Calcareous tufa.) Ibid., p. 797.
5. Millen Portland Cement Company, Wayland, Steuben County.
6. Genesee Wayland Portland Cement Company, Perkinsville, Steuben County.
7. American Cement Company, Jordan, Onondaga County.
8, 9. Empire Portland Cement Company, Warners, Onondaga County.
10. Montezuma, Cayuga County. Mineral Industry, vol. 1, p. 52.
11. Canastota, Madison County. Bull. New York State Mus., No. 44, p. 794.

PORTLAND-CEMENT INDUSTRY.

EARLY HISTORY.

Portland-cement manufacture in New York State started only a few years after cement making had been begun in the Lehigh district of Pennsylvania. The history of the New York industry was, however, entirely distinct from that of the Lehigh district. Men, materials, and methods were different, and in consequence the early history of the New York industry contains much of interest. A brief sketch of that early history is given in the following pages. For the data contained in this sketch the writer is indebted to Messrs. J. Gardner Sanderson and Edward Duryee, who placed at his disposal much material concerning the early plants with which they were connected.

The earliest experiments in the manufacture of Portland cement in this State appear to have been those carried on in the Rosendale region about 1875–76. They were made by a Mr. Dunderdale at East Kingston, Ulster County, Messrs. Cornell and Coykendall furnishing the capital. The materials used were marl, brought by way of the Erie Canal from the Montezuma marshes, and a clay obtained near the plant. Cement of a very high grade was manufactured, but the materials and processes used were of too expensive a character to permit the experiment to become financially successful. The details of the experiments are not at present obtainable, but some idea of the

methods followed and of the general high quality of the product may be gained from the following extract from the published report of Gen. Q. A. Gillmore, on the cements exhibited at the Philadelphia Exposition of 1876:

It is deemed proper as a subject of general interest to refer briefly to some cements not represented in the exhibition.

The National Portland Cement Company, of Kingston, Ulster County (N. Y.), has recently been organized for making Portland cement by the fourth method above described.[a] The materials employed are fuller's earth, kaolin, and lime. They are thoroughly ground and mixed together in suitable proportions by the wet process, although much less water is used than in the English works or in those at Boulogne. The mixture when completed is in a rather stiff semiliquid state. In this condition it is run out upon a floor underlaid with warming flues, where it is dried to the state of tempered brick clay. It is then passed through a brick machine, and subsequently burnt in common continuous upright kilns with anthracite coal.

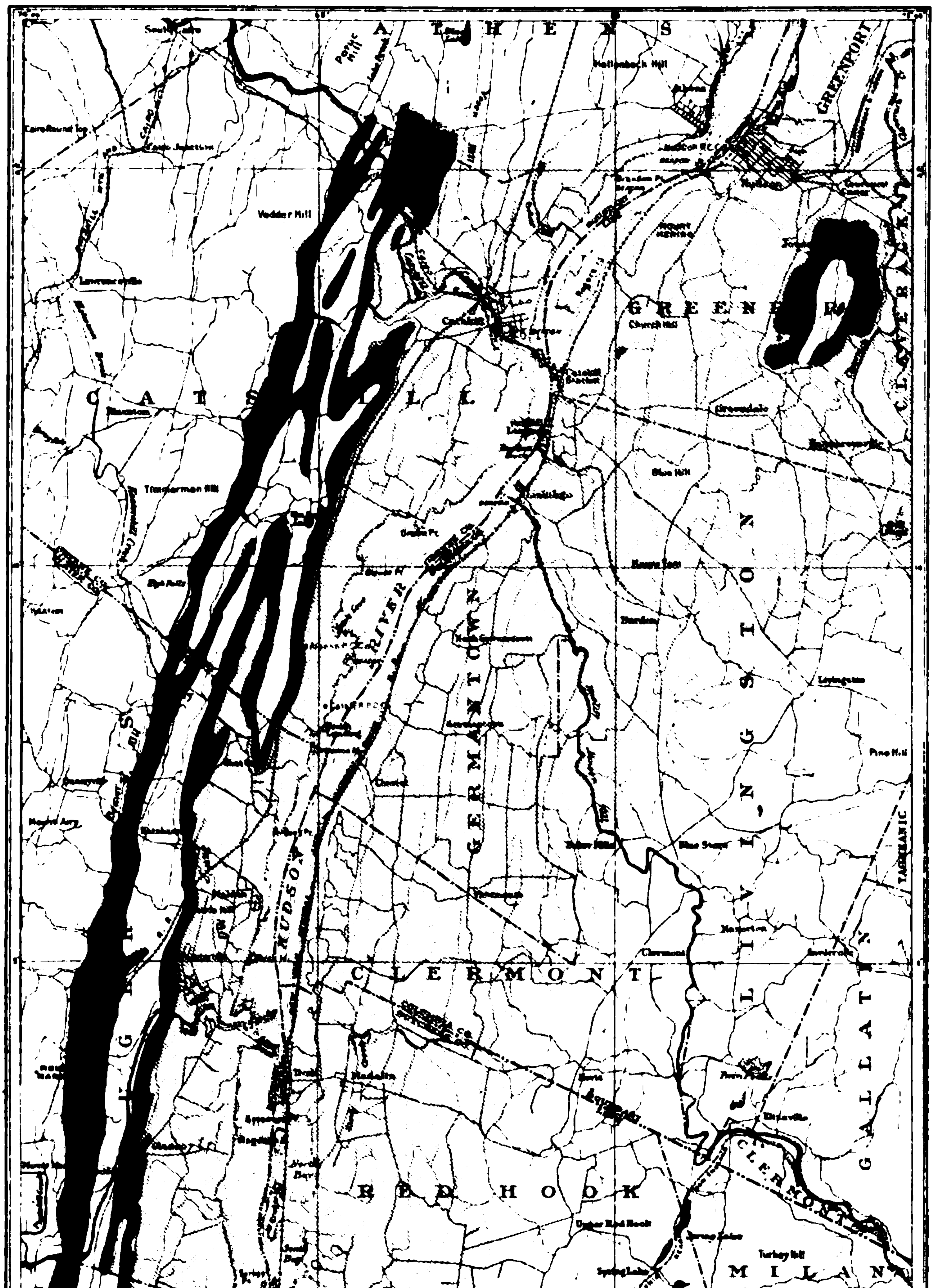
Specimens of this cement have been tested several times by the writer with excellent results. On the last occasion the method adopted with the cements in the exhibition was strictly followed. One and one-half inch cubes seven days old, composed of equal parts of dry cement and sand, gave a crushing strength of 3,335 pounds per cube as an average of 20 trials, being a little higher than the best Portland cement exhibited, as shown by the table.

Succeeding this in point of date was a small plant at Low Point, Dutchess County, erected by the engineer and contractor for the first Poughkeepsie bridge. Some cement was made here and used in the tower foundations, but the failure of the bridge project also ended the cement experiments.

During the winter of 1877–78 Messrs. J. Gardner Sanderson and T. T. Crane carried on a series of experiments at Croton-on-the-Hudson. A small upright kiln was in use, with a Bogardus mill and the power which during the summer was used in brickmaking. These experiments and the analysis of a large number of specimens of possible materials convinced the experimenters that the Hudson River limestones generally contained too high a percentage of magnesium carbonate, and the clays too much free sand, to be suitable ingredients of a Portland cement. Certain strata of limestone, however, belonging to the Helderberg groups[b] (see Pl. XI), the outcrops of which extend approximately north and south a short distance west of Hudson River, crossing Rondout Creek near South Rondout, were found to be remarkably pure and free from magnesia and well adapted to their purpose. As above stated, most of the clay deposits near Hudson River carried too much sand to be of use. After careful search suitable clays were found away from the river, the best being found in an extensive deposit near Phœnicia, on the Ulster and Delaware Railroad.

[a] This "fourth method" here noted was, as described on a preceding page of the report, the double-kilning process, in which the calcareous material was burned and slaked before being mixed with the clay.

[b] Limestone from the same horizon is now being used in the manufacture of Portland cement by two companies, the Catskill Cement Company and Alsen's American Portland Cement Company, both plants being situated a short distance south of Catskill.



MAP OF THE HUDSON RIVER PORTLAND-CEMENT DISTRICT, NEW YORK

SHOWING LOCATIONS OF CEMENT PLANTS AND OF AVAILABLE LIMESTONES AND SHALES

Geology compiled from maps by N. H. Darton and W. H. Davis

Scale 0 1 2 3 4 miles

1906

LEGEND

DEVONIAN — Onondaga or upper Helderberg limestones

SILURIAN — Lower Helderberg and Salina limestones

ORDOVICIAN AND CAMBRIAN — Shales (often covered near the river by Quaternary clays and sands)

Location of Portland-cement plants

Location of quarries for Portland-cement limestone

In 1880 the Wallkill Portland Cement Company was organized. The limestone and clay properties above referred to were purchased, and an abandoned flour mill at Carthage Landing, on the Hudson, was leased and equipped with suitable machinery, a drying channel, and two upright kilns. The manufacture of Portland cement was commenced at these works early in 1881. The product, though small in quantity, was of excellent quality and had a ready sale. Tests and reports by Messrs. Clark and Maclay demonstrated the value of the cement, and the experimenters were satisfied that the manufacture could be made commercially successful on a larger scale. At both the Low Point and Carthage Landing plants gas-house coke was used for fuel.

Average analyses of the clay and limestone used are given later in this paper in discussing the operations at South Rondout. A typical analysis of the cement made at Carthage Landing follows:

Analysis of cement made at Carthage Landing, N. Y.

Lime	59.43
Magnesia	1.72
Peroxide iron	5.17
Alumina	8.13
Silica	24.10
Water, alkalies, etc	1.45
	100.00

In the latter part of 1881 work was commenced on a plant located on the limestone property near South Rondout, and works with a capacity of 200 to 300 barrels a day were put in operation in 1883. These works were equipped with Blake crushers, cone grinders, buhrstone mills, mixers, and formers. Sixteen upright dome kilns were in use, with a drying channel connected and heated by the waste gases from the kilns. The limestone and clay were crushed, ground, and mixed dry, then steamed and formed into bricks, which were loaded on iron cars and run by gravity through the drying channels.

For some time after cement manufacture had been in progress at these works the gas companies of New York and Albany had supplied the coke necessary for burning the material, but the introduction of the water-gas process cut off this source of fuel supply. This left the plant dependent upon Pennsylvania coke, the cost of transportation and handling of which increased the cost of cement manufacture very largely. Mr. Sanderson therefore commenced experiments on the use of crude Lima oil as fuel, but found that the clinkering of the cement materials in front of the burners prevented the heat from entering the charge. Knowing that this same difficulty had been met in metallurgic operations and overcome by the use of rotary furnaces, he directed his attention toward such furnaces or kilns as presenting a possible solution of the problem.

The kiln adopted was a form which had been patented in 1881 by

Dr. George Duryee, of New Jersey. In October, 1888, one kiln was put into operation at the South Rondout works. This kiln was 50 feet long and 50 inches in diameter. The upper end was at first made 50 inches higher than the lower end, but later this was reduced to 30 inches. On trial this was found to be a very satisfactory method of burning, the one kiln handling all the material the mill could supply and producing a uniform and high-grade product. Of still greater importance was the fact that it was found possible to charge the mixed and ground raw material directly to the kiln without preliminary wetting, making into bricks, and drying. This was the first American plant at which this practice of direct charging was followed.

In 1889 the plant was entirely destroyed by fire, and Portland cement manufacture in the lower Hudson Valley ceased till 1900.

The following notes from the Rondout records establish some dates:

October 25, 1888.—Burned about 100 barrels to-day; oil fuel. Ground the limestone and clay separately dry, and mixed before feeding to kiln. Mixture—clay, 21 pounds; limestone, 80 pounds.

February 25, 1889.—Mixture burned—clay, 21 pounds; limestone, 100 pounds.

Analysis of resulting cement.

Lime	65.96
Silica	18.53
Alumina and oxide of iron	11.09
Potash	.12
Soda	.62
Carbonic acid	.97
Magnesia and undetermined	2.71
	100.00

Physical tests of tensile strength.

7 days=253 pounds.
14 days=466 pounds.
Second tests:
  7 days=306 pounds.
  10 days=509 pounds.

Representative analyses of the limestone and clay used at the Carthage Landing and South Rondout plants are as follows:

Analyses of limestone and clay used for cement making.

	Limestone.	Clay.
Lime	52.295	1.255
Magnesia	.5	2.37
Peroxide iron	.438	9.144
Alumina	.677	20.771
Silica	4.405	54.011
Carbonic acid	41.515	.4
Water and alkalis	.17	12.049
	100.00	100.00

In the fall of 1890 operations were commenced at Montezuma, N. Y. The company owned 1,700 acres of land, underlain by a deposit of marl and clay, which varied in thickness from 4 to 20 feet. The deposit lay below the level of Cayuga River and near its shores. It was overlain by several feet of muck, which was first dredged off and used for filling and grading for a railroad. The marl and clay had a rather uniform composition, and it was therefore found practicable to excavate both materials by machinery. The bucket of the steam dredger employed brought up a ton every three minutes. Cars were run on the track under the bucket of the dredge to receive the material, and the loaded cars were then run on platform scales and weighed.

The marl, containing about 50 per cent water, was drawn by a steam hoist up an incline into the second story of the works and above the upper end of a mixing machine, into which the load was dumped without drying or any other preliminary treatment. At the same time a weighed and ground portion of clay was added to standardize the mixture. The materials mixed as they gravitated toward the lower end of the machine. The entire process was practically continuous, a fresh charge being added at the upper end of the mixer every ten minutes, while an equal amount was being gradually drawn off from the lower end in the same space of time. The mixture then passed to a stone mill that completed the mixing and ground any coarse materials. From the mill the mixture was introduced directly by a screw conveyer into the rotary kiln, oil being used as fuel. This was unique not only in its length, 75 feet, but in having opposite its lower end a gas retort or combustion chamber. This chamber was heated by a coal fire and vaporized the oil as it was sprayed into it. The air blast also passed into this chamber, coming from a rotary fan blower.

In the first volume of Mineral Industry Mr. W. A. Smith gives the following interesting contemporary account of this kiln:

> Duryee's revolving furnace consists of a sheet-iron cylinder, 75 feet long, inclined toward the firing end $\frac{3}{8}$ inch to 1 foot. The lower hot end is 6 feet in diameter for a length of 20 feet, and is lined 9 inches thick with a mixture of ground fire brick and molasses. The remainder of the cylinder, 55 feet long, has a diameter of 5 feet, and is lined with 6-inch fire brick. Only the lining at the hot end requires renewal, and this can be replaced in ten hours, at a cost of $25. The cylinder revolves on cast-iron rollers three times a minute. The power required is 5 horsepower.
>
> At the lower end a small coal fire is kept up on a grate, but the chief fuel is crude petroleum, introduced in a jet which meets the hot-air blast. The consumption of oil is 8 gallons per barrel of cement clinker produced. Fifteen barrels of oil are required to heat the furnace ready for burning cement.
>
> The clay and marl are mixed wet and run in as a slurry at the upper end. The mixture in drying forms a sand, which moves slowly downward with the turning of the cylinder, and is finally discharged at the lower end as cement clinker of the size of small gravel. It takes two hours to run the particles through. The operation is continuous, and the product is 250 barrels per day. It is claimed that all the mixture is burned to Portland clinker.

From a series of analyses and tests, furnished by Mr. Duryee, the following have been selected:

Analyses of materials used and resulting product at Montezuma.

	Marl.[a]	Clay.	Cement.
Lime (CaO)	47.68	....	62.22
Silica (SiO_2)	6.22	59.22	22.51
Alumina (Al_2O_3)	1.70	20.82	9.17
Iron oxide (Fe_2O_3)	.66		2.54
Magnesia (MgO)	.52	3.09	1.08
Carbon dioxide (CO_2)	42.11	....	1.86

[a] Calculated without moisture.

A report by Mr. W. W. Maclay, dated April 28, 1892, gives the average tensile strength obtained, as follows:

	Pounds.
Neat, 7 days	649
Mortar (1:2), 7 days	245
Mortar (1:2), 28 days	418

The works at Montezuma were entirely destroyed by fire in June, 1893, and have never been rebuilt. The plant is of particular interest because of the advanced technologic methods there employed. It was the first American plant in which wet raw materials were fed, without drying or briquetting, directly into rotary kilns.

Conclusion.—The history of the above plants, which bore a certain relationship to each other either in locality or management, overlaps, in point of date, the beginning of the present system of New York cement plants. The destruction by fire of the South Rondout and Montezuma plants terminated the connection of the early experimenters with New York's cement industry, and the early history of that industry may be said to end in 1893. As early as 1886 another Portland plant had been erected, but this plant was managed by an Englishman, and the problem was attacked in an entirely different manner. The earlier plants had been aggressively original and American; the plant at Warners, with its dome kilns and wet mixing, was ultra-English. Until within the last few years the typical New York plant has been one using marl and clay,[a] mixing wet, briquetting and drying, and burning in dome kilns. The Warners Portland Cement Company erected a rotary-kiln plant near Warners, Onondaga County, but it was in operation only a short time, and has been shut down since 1894.

[a] There was, in fact, but one exception to this rule. The Glens Falls Portland Cement Company, at Glens Falls, Warren County, has operated Schöfer kilns since 1894 on limestone and clay.

PRESENT CONDITION.

Ten Portland cement plants are now in operation in New York State. One employs Trenton limestone and clay, four use Helderberg limestones with clay or shale, one uses Tully limestone and shale, and four employ marl and clay. Another plant, using marl and clay, has been idle for some years, but is described below.

Alsen's American Portland Cement Works are located at West Camp, or Alsen station, Greene County, near the plant of the Catskill Cement Company. The materials used are the Becraft limestone, of the lower Helderberg, and clays of Quaternary age. As usual with these clays along the Hudson River considerable trouble has been encountered in using them for cement material. Excellent shales, however, occur in the immediate vicinity of the plant, and these can be used with the limestone. The latter is of the usual composition of the Becraft, high in lime carbonate (about 95 per cent) and low both in clayey matter and magnesium carbonate.

The plant of the American Cement Company, located 2 miles east of Jordan, Onondaga County, was erected in 1892. The works were operated without interruption until 1900, when they were shut down, owing to new construction by the company at Egypt, Pa.

The materials used were marl and clay, both obtained from a marsh near the works, another bed of marl being owned by the company nearer to Jordan station. The marl is white, and the bed varies in thickness from 8 to 15 feet. It is overlain by a thin bed of muck and underlain by a blue clay. The muck being stripped, the marl and clay were dug and transported to the works by a wire ropeway. The clay was dried and ground separately, after which it was mixed with the marl in pug mills. The resulting slurry was spread out on a drying floor and cut into bricks. These bricks were then loaded on platform cars, dried in tunnels heated by coal fires, and fed to the kilns. Twelve kilns, of the dome type, were in use, coke being used as fuel.

The clinker was reduced, first in Gates and Mosser crushers, and finally in Griffin mills. The cement was marketed as the Giant (Jordan) brand. The following analyses of the raw materials and finished product were furnished by the company:

Analyses of cement materials used by American Cement Company, Jordan, N. Y.

	Marl.	Clay.	Cement.
Silica (SiO_2)	0.14	65.68	21.86
Alumina (Al_2O_3)	.36	24.08	7.17
Iron oxide (Fe_2O_3)			3.73
Lime (CaO)	53.16	2.01	61.14
Magnesia (MgO)	1.50	1.75	2.34
Sulphur trioxide (SO_3)	....	....	1.94

The Portland plant of the Catskill Cement Company, located at Smiths Landing, Greene County, was erected in 1899 and shipments were commenced in July, 1900. The materials used are clay from the river terraces and limestone of Helderberg age. A bucket cableway is used to transport the raw materials from the quarry and clay bank to the works. The following average analyses of these materials were furnished by the company:

Analyses of limestone and clay used by Catskill Cement Company.

	Limestone.	Clay.
Silica (SiO_2)	1.54	61.92
Alumina (Al_2O_3)	.39	16.58
Iron oxide (Fe_2O_3)	1.04	7.84
Lime (CaO)	53.87	2.01
Magnesia (MgO)	.52	1.58
Alkalies	.00	3.64
Sulphur trioxide (SO_3)	.00	Trace.

The limestone is dried and then reduced in a Smidth ball mill. The clay is passed through a roll disintegrator and is dried. The materials are at this stage mixed dry, and the mixing and reduction are completed in Davidsen tube mills. Two rotary kilns are in operation, having a total capacity of about 300 barrels a day. The clinker is crushed in ball mills and receives its final reduction in tube mills. The cement is marketed as the "Catskill" brand. The following analyses of the finished product were furnished by the company, 1 and 2 having been made in their laboratory, while 3 was made by H. E. Keifer:

Analyses of cement made by Catskill Cement Company.

	1	2	3
Silica (SiO_2)	22.48	21.94	23.44
Alumina (Al_2O_3)	6.52	6.02	6.35
Iron oxide (Fe_2O_3)	4.46	4.38	3.99
Lime (CaO)	62.93	64.62	63.21
Magnesia (MgO)	1.48	1.25	1.15
Sulphur trioxide (SO_3)	1.30	1.12	1.22

The plant of the Cayuga Portland Cement Company is located at Portland Point, Tompkins County, on the east shore of Cayuga Lake. The materials used are the Tully limestone and shales of the underlying Hamilton group.

The following analysis, by J. H. McGuire, chemist of the Cayuga plant, shows the composition of the limestone and shale used here.

Analyses of cement-making material used by Cayuga Portland Cement Company.

	Limestone.			Shale.		
Silica (SiO_2)	9.72*	6.30	7.88	58.44	57.82	60.02
Alumina (Al_2O_3)	4.20	3.35	4.01	27.45	21.76	26.60
Iron oxide (Fe_2O_3)	.48					
Lime (CaO)	47.11	50.25	48.10	1.16	8.32	2.31
Magnesia (MgO)	.66	.22	.53	2.23	1.81	1.62

In 1886 T. Millen & Sons commenced the manufacture of Portland cement at Warners, Onondaga County. In 1890 the plant was purchased by the Empire Portland Cement Company and the works were almost entirely rebuilt, a much larger output being secured by the improvements then introduced. Since that date the plant has been in constant operation, with the exception of stops aggregating only some five or six weeks in all, caused by fires.

The materials used are marl and clay, obtained from a swamp in the vicinity of Warners, the present workings being located about three-fourths of a mile from the works. The marl bed covers an area of several hundred acres, of which about 100 acres have already been excavated. A revolving derrick with clam-shell bucket is employed for excavating the marl, the clay being dug by hand. The materials are taken to the works over a narrow-gage railway owned by the company, on cars carrying from 3 to 5 tons each, drawn by a small locomotive. At the works the cars are hauled up an inclined track by means of a cable and drum to the mixing floor.

The swamp from which the raw materials are obtained shows sections, from top to bottom, approximately as follows:

Section in swamp at Warners, N. Y.

	Feet.
Muck	1–2
Upper bed, white marl	4–7
Lower bed, gray to brown marl	4–7
Sand	0–1
Bluish clay	2–5

As might be expected from the relative color of the marls, the material from the lower bed shows on analysis more organic matter than that from the upper bed, for which reason more of it must be used with the same amount of clay than of marl from the upper bed. This distinction is accompanied by other slight but rather constant differences in chemical composition, which have also to be taken into account in the preparation of the cement mixture.

Analyses 1 and 3, below, are quoted by Cummings (American Cements, p. 253), while 2 and 4 were furnished by the Empire company.

Analyses of cement-making material used at Warners, N. Y.

	Marl.		Clay.	
	1	2	3	4
Silica (SiO_2)	0.26	0.26	40.48	42.85
Alumina (Al_2O_3)	.10	.21	20.95	13.51
Iron oxide (Fe_2O_3)		.01		4.49
Lime carbonate ($CaCO_3$)	94.39	91.03	25.80	22.66
Magnesium carbonate ($MgCO_3$)	.38	.40	.99	6.92
Potash (K_2O)	....	....	3.14	3.08
Sulphur trioxide (SO_3)	....	....	....	2.85
Organic	1.54	1.68	8.50	....
Water+loss	3.10	6.30		

This clay runs higher in lime than any other used in the State, the clay showing the nearest approach to it being that used at Wayland, which carries a little less than 20 per cent of lime carbonate.

Of the analyses of the Empire brand below, 1 is quoted by Cummings (American Cements, pp. 36), 2 by Lewis (Mineral Industry, VI, pp. 99), while 3 was furnished directly by the company.

Analyses of cement made by Empire Cement Company, Warners, N. Y.

	1	2	3
Silica (SiO_2)	20.80	22.04	21.98
Alumina (Al_2O_3)	7.39	6.45	8.20
Iron oxide (Fe_2O_3)	2.61	3.41	3.70
Lime (CaO)	64.00	60.92	61.83
Magnesia (MgO)	....	3.53	1.43
Alkalies	....	....	.84
Sulphur trioxide (SO_3)	....	2.73	1.18

In 1893 the Glens Falls Portland Cement Company commenced the erection of a plant at Glens Falls, Warren County, and its cement was put on the market in 1894, as the "Iron Clad" brand. Six shaft kilns of the Schoefer type were installed, the Glens Falls plant being therefore the second in this country to make use of this type of kiln. Though highly economical in fuel, the kiln is rather expensive in both the quantity and quality of manual labor required to operate it properly. A fire in August, 1899, destroyed the plant, which was rebuilt to give a nominal capacity of 500 barrels a day, and the manufacture of cement was recommenced in August, 1900.

The materials used are limestone and clay. The former is of Trenton age, and is obtained from the Glens Falls quarries. Considerable care is required in selecting and mixing the stone from the various layers, in order to obtain a suitable and uniform product. A very clean and uniform clay, overlying the limestone in this area, is the other ingredient. The composition of these materials is shown below.

Analyses of cement-making materials used at Glen Falls, N. Y.

	Limestone.	Clay.
Silica (SiO_2)	3.30	55.27
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	1.30	28.15
Lime (CaO)	52.15	5.84
Magnesia (MgO)	1.58	2.25
Sulphur trioxide (SO_3)	.30	.12
Carbon dioxide (CO_2)	40.98	....
Organic and water	8.37	....

The limestone and clay are separately dried, and crushed in Blake crushers and rolls. After being weighed on automatic scales, the materials are mixed dry and reduced to a fine powder in Griffin mills. The powder is then fed into wet mixers, where sufficient water is added to allow it to be made up into bricks. These are dried in tunnels heated by waste heat (from the boiler) driven through the tunnel system by blowers. After drying, the bricks are burned in Schoefer kilns, coal being used as fuel. The clinker is passed first through Smidth ball mills and finally reduced in Davidsen tube mills.

An average analysis of the Iron Clad cement is given below.

Analysis of cement made at Glen Falls, N. Y.

Silica (SiO_2)	21.50
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	10.50
Lime (CaO)	63.50
Magnesia (MgO)	1.80
Potash and soda (K_2O and Na_2O)	.40
Sulphur trioxide (SO_3)	1.50

HELDERBERG CEMENT COMPANY.

The plant of the Helderberg Cement Company is located at Howe's Cave, Schoharie County. Quarries in the Salina or Waterlime group at this point have been long used for the manufacture of natural cement, while quarries higher up, both geologically and topographically, furnished a very pure limestone, which was burned into lime.

In 1898 the Helderberg Cement Company began to utilize the stone from these latter quarries in the manufacture of Portland cement. Commenced on a small scale, the industry would seem to have promised favorable results, as a much larger plant, belonging to the same company, was erected during 1900 and has recently started operations. The new plant has a nominal capacity of 1,500 barrels a day. The materials used are limestone and clay.

As noted below, the limestone used for Portland cement is obtained from the old lime quarries and the clay from a Quaternary deposit in the vicinity. Smidth ball mills and Davidsen tube mills are used for crushing, reducing, and mixing the materials. The wet process is employed, and twelve rotary kilns are in use. The resulting clinker is ground in ball mills and tube mills, and the product is marketed as the "Helderberg" brand.

The limestone used in Portland-cement manufacture is obtained from the Becraft and Manlius beds, exposed in quarries just west of the station, on the northern side of the railroad track. Partial analyses of these limestones, quoted by Prosser as having been made by C. A. Schaeffer, follow.

Analyses of limestones used at Howes Cave, N. Y.

	SiO_2	$CaCO_3$
Manlius limestone	1.48	95.75
Becraft limestone	4.12	93.68

Another sample analyzed by Schaeffer gave the results stated below.

Analysis of limestone used for making cement at Howes Cave, N. Y.

Silica (SiO_2)	1.27
Alumina (Al_2O_3) Iron oxide (Fe_2O_3)	.73
Lime carbonate ($CaCO_3$)	97.24
Magnesium carbonate ($MgCO_3$)	1.39
Sulphur trioxide (SO_3)	Trace.

The plant of the Hudson Portland Cement Company is located in the city of Hudson, Columbia County, and is therefore the only cement plant in the United States situated east of the Hudson River. The limestone used here is obtained a few miles from the plant from an outlying area of the Becraft (lower Helderberg) limestone, known as Becraft Mountain. Quaternary clays and shales of Hudson (Ordovician) age are used to complete the mixture. The plant itself was recently constructed, and at present ten kilns are operated. Analyses by Herberg and Roney of the clays and shales used here follow.

Analyses of cement-making materials used at Hudson, N. Y.

	Shale.		Clay.		
Silica (SiO_2)	54.70	64.30	58.90	52.00	52.10
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	31.68	33.60	27.50	31.00	35.56
Lime (CaO)	1.15	1.46	4.08	7.10	5.90
Magnesia (MgO)	n. d.	1.30	.79	3.33	3.33

The Iroquois Portland Cement Company has recently built a plant near Caledonia, Livingston County. Marl from a deposit near the plant is mixed with clay brought from Canawangus, Genesee County. Both materials are dried before mixing. Analyses of the raw materials follow:

Analyses of cement-making materials used near Caledonia, N. Y.

	Marl.	Clay.
Silica (SiO_2)	0.4	62.5
Alumina (Al_2O_3)	.2	20.2
Iron oxide (Fe_2O_3)	.2	7.5
Lime (CaO)	53.5	.8
Magnesia (MgO)	.3	1.8
Sulphur trioxide (SO_3)	1.7	.4

After having disposed of their plant at Warners, Onondaga County, to the Empire Portland Cement Company, T. Millen & Co. erected their present plant at Wayland, Steuben County, which commenced producing in October, 1892. The works were destroyed by fire in July, 1893, but were rebuilt and began shipping again in October, 1893.

The materials used are marl and clay. The marl is obtained from a swamp near the mill, about 185 acres of marsh land being owned by the company. The marl deposit is about 6 feet thick. Unlike the Onondaga County deposits, however, the marl bed is not underlain by clay, and the latter material has to be brought from a bank near Mount Morris, in Livingston County. The clay deposit there worked is one of a series which occur in the terraces bordering Canaseraga Creek and Genesee River, extending more or less continuously from Dansville nearly to Rochester. The clay for cement is worked at a point about 4 miles south of Mount Morris, and is shipped over the Delaware, Lackawanna and Western Railroad to the works, a distance of about 20 miles.

The clay is dried over steam coils, ground in a Potts disintegrator, and mixed with the marl in a revolving mixer. The slurry is then passed through pug mills and made into bricks. These bricks are

dried in tunnels and burned in dome kilns, 16 of which are in operation. Blake crushers, Millen crackers, and Sturtevant rock emery mills are used in the reduction of the clinker. The cement is marketed as Millen's Wayland.

Analyses of the raw materials and of the finished product, furnished by the company, follow.

Analyses of clay, marl, and cement, Mount Morris, N. Y.

	Clay.	Marl.	Cement.	
Silica (SiO_2)	45.21	0.42	21.08	22.19
Alumina (Al_2O_3)	19.08	1.08	9.56	9.72
Iron oxide (Fe_2O_3)	6.74			
Lime carbonate ($CaCO_3$)	19.94	93.5	....	....
Lime (CaO)	....	....	64.68	63.08
Magnesium carbonate ($MgCO_3$)	3.27	2.13	....	....
Magnesia (MgO)	....	....	1.85	2.04
Lime sulphate ($CaSO_4$)	1.55	2.01	....	....
Sulphur trioxide (SO_3)	....	....	1.93	1.75
Moisture and organic matter	4.17	.86	....	....
Alkalies and loss	....	....	.9	1.22

The analyses of the clinker were made for the company by Dr. F. E. Engelhardt, of Syracuse, N. Y.

The plant of the Wayland Portland Cement Company is located at Perkinsville, in the town of Wayland, Steuben County. It was erected in 1896 and has operated continuously to date.

The materials used are a light-colored marl, found in a deposit 2 to 14 feet thick, overlain by 6 inches to 3 feet of muck, which occurs in a marsh near the works, and light-gray (Pleistocene) clay from Mount Morris, Livingston County. The marl here, as at Millen's, is not underlain by clay. The following analyses of the raw materials were furnished by the company:

Analyses of marl and clay from Mount Morris, N. Y.

	Marl.	Clay.
Silica (SiO_2)	0.54	53.5
Alumina and iron oxide (Al_2O_3 and Fe_2O_3)	.56	24.2
Lime (CaO)	54.4	5.15
Magnesia (MgO)	2.34	2.15
Loss on ignition	42.2	14.1

The clay is dried over steam pipes, broken to about one-fourth to one-half inch size in a Potts disintegrator, and sent through a

Bullock buhrstone mill, which grinds to about 16 mesh. It is then weighed and mixed with the wet marl as both are shoveled into the chutes leading to the revolving mixer. The mixture then goes to the pug mills and is made into bricks, which are sent to the drying tunnels. The lower tier of these tunnels is heated by direct heat, on the Cummer system; the upper tier by exhaust steam. Sixteen dome kilns are in use. From the kilns the clinker goes to an 18 by 30 inch Blake crusher; then to dry pans, receiving its final reduction in Sturtevant rock emery mills. The product is marketed as the Genesee Wayland brand.

Two firms in New York State manufacture, in addition to their natural cements, brands which are marketed as "natural Portlands." The limestone is fed, without previous grinding or admixture, direct to the kilns. As the limestone used carries, as shown by analyses of their natural cements, an amount of magnesia (over 8 per cent in the finished product), at present considered inadmissible in a Portland, the value of the resulting cements is problematical. From laboratory tests it would seem that they can usually pass all Portland requirements, though rather low in tensile strength on short-time tests. Concerning the qualities which they develop when used in actual work, no information has been obtained; but the cements can not be worse than some of the poorer foreign Portlands which are unloaded upon the American market. Cements of this type can, of course, be placed upon the market profitably at a price only slightly above that of "natural" cements, the only additional cost being due to a little extra expense in grinding the clinker.

PORTLAND-CEMENT RESOURCES OF NORTH CAROLINA.

No cement plants have ever been operated in North Carolina, and the State will probably never be an important cement producer, because of the conditions as to fuel and the lack of local markets. If commercial conditions should justify the erection of a cement plant, however, good raw materials are available.

The limestones suitable for cement manufacture in North Carolina fall into two classes, distinct geographically as well as geologically. There are (1) the crystalline limestones of western North Carolina; (2) the soft limestones of eastern North Carolina.

CRYSTALLINE LIMESTONES.

In the extensive area of metamorphic and igneous rocks, that covers the western half of North Carolina, outcrops and beds of crystalline limestones or marbles are common. Many of these marbles are highly magnesian in composition, but the specimens used for the analyses given below were low in magnesia.

Analyses of crystalline limestones, North Carolina.

	1	2
Silica (SiO_2)	1.20	2.93
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	.82	1.17
Lime (CaO)	52.90	49.83
Magnesia (MgO)	1.91	3.61

1. Culberson quarry, 11 miles southwest of Murphy, Cherokee County.
2. Kinsey quarry, 5 miles southwest of Murphy, Cherokee County.
Baskerville, analyst. Bull. North Carolina Geol. Survey No. 1, p. 233.

So far as composition goes, these are certainly satisfactory enough for use in cement manufacture, but commercial considerations would prevent the erection of a Portland cement plant in this part of the State.

SOFT LIMESTONES.

In the eastern part of North Carolina heavy beds of soft limestone occur in the Eocene and Miocene formations of the coastal plain. These soft limestones are the "marls" of early geological reports, but should not be confused with the fresh-water marls now so largely used as cement materials. The North Carolina limestones are usually low in magnesia, but often contain considerable percentages of clayey matter or of sand. A deposit free from sand would be an excellent material for use in making Portland cement, and clays to complete the mixture can readily be obtained in the same formations.

Analyses of soft limestones ("marls"), North Carolina.

No.	Silica (SiO_2).	Alumina (Al_2O_3); iron oxide (Fe_2O_3).	Lime (CaO).	Magnesia (MgO).	Alkalies (K_2O, Na_2O).	Sulphur trioxide (SO_3).	Carbon dioxide (CO_2).	Water and organic matter.
1	4.88	1.60	50.80	0.67	1.79	0.33	40.60	0.27
2	7.27	5.23	48.55	1.39	1.06	.20	39.35	.45
3	3.54	.97	51.74	.50	1.64	.49	40.61	.16
4	4.56	1.62	50.04	1.72	.14	.45	40.55	.58
5	6.97	.86	47.62	1.03	.52	.41	38.15	4.25
6	26.35	5.47	33.03	.59	.93	.28	24.89	6.89
7	20.39	3.83	39.96	1.42	.79	.24	32.46	.52
8	7.27	1.63	48.55	1.39	1.06	.20	39.35	.45
9	1.22	1.30	52.90	1.07	.30	.08	42.33	.46
10	3.54	.97	51.74	.50	1.64	.49	40.61	.16
11	4.95	2.30	50.59	.58	.85	.18	40.29	.26

1. Near Kinston, Neuse River.
2. Twenty-five miles north of Wilmington.
3. Wilmington.
4. Near Newberne.
5. Lumber River, Robeson County.
6. Cape Fear River, 25 miles north of Wilmington.
7. Kenansville, Duplin County.
8, 9. Two miles above Rocky Point, New Hanover County.
10. One mile northeast of Wilmington, New Hanover County.
11. One mile west of Rocky Point, New Hanover County.
1 to 6. Bogardus and Hanna, analysts; vol. 6, Tenth Census Reports, p. 554.
7 to 11. Quoted by Kerr, Rept. Geol. Survey North Carolina, vol. 1, pp. 191.

PORTLAND-CEMENT RESOURCES OF NORTH DAKOTA.

Only one limestone formation of any importance—the Niobrara chalk, of Cretaceous age—is found in North Dakota, and even this is almost entirely concealed by a thick covering of drift. The Niobrara chalk is the formation which is now utilized for Portland-cement manufacture at Yankton, S. Dak., while it gives promise of being a future source of cement material in Nebraska and Iowa.

The physical characters and chemical composition of the Niobrara chalk throughout various portions of its range are fully described in the text relating to deposits in the States above mentioned, and analyses will be found on pages 148 and 301. It is of peculiar value as a Portland-cement material, both because of its softness, which permits it to be easily crushed and pulverized, and because of its usual freedom from magnesia and other injurious ingredients. Outcrops of the Niobrara chalk, moreover, are commonly capped by clays of the Pierre group, which furnish admirable materials for mixing with the chalk.

Portland cement manufacture has been attempted at only one point in North Dakota, and here the Niobrara chalk was found to be too low in lime to be used for this purpose. Analyses of the materials at this point will be found in the section on natural cement, page 352.

PORTLAND-CEMENT RESOURCES OF OHIO.

PORTLAND-CEMENT MATERIALS.

The geologic groups which contain low-magnesia limestones in Ohio are the following:

(1) Trenton limestone.
(2) Cincinnati series of limestones and shales.
(3) Clinton limestone.
(4) Corniferous (Devonian) limestone.
(5) Maxville (Mississippian) limestone.
(6) Ferriferous and other Coal Measure (Pennsylvania) limestones.
(7) Quaternary marls.

The distribution throughout the State of the first six of these limestone groups is shown on the map, Pl. XII.

TRENTON SERIES.[a]

This series consists of shale and pure limestone. It outcrops as a narrow strip along the Ohio River from the mouth of the Little Miami to a point a mile or two above New Richmond. This is the formation that the Mentor plant on the south side of the Ohio River has been planned to use.

In view of the cheapness of fuel and transportation, the abundance and its general excellence of material, and the ease with which it may be procured, the strips bordering the Ohio River from Madison, Ind., to Maysville, Ky., seem to offer unusually promising locations for Portland cement plants.

[a] Most of the notes on the Trenton and Cincinnati limestones were contributed by Mr. E. O. Ulrich of the U. S. Geol. Survey.

CINCINNATI GROUP.

This series may be separated into three well-marked divisions or groups. The lower division, about 250 feet thick, consists almost entirely of shale; the middle division, 200–250 feet thick, contains numerous layers of limestone from 3 feet to 20 feet thick, the lower half constituting the "Hill Quarry beds" at Cincinnati. The upper division (Richmond group) consists of numerous alternating beds of soft shale and limestone, with usually a heavy bed of shale at the base and top.

Analyses of Trenton and Cincinnati limestones, Ohio.

No.	Silica (SiO_2).	Alumina (Al_2O_3); iron oxide (Fe_2O_3).	Lime (CaO).	Magnesia (MgO).	Carbon dioxide (CO_2); water.
1	23.48	3.40	39.93	0.91	32.35
2	10.80	1.40	48.50	.54	38.69
3	7.04	[a] 3.78	49.28	.98	38.72
4	12.00	7.00	44.41	.44	35.36

[a] Alumina, 2.48; iron oxide, 1.30.

1. Limestone in Trenton series, river quarries, Cincinnati. Wormley, analyst. Geol. Survey Ohio, vol. 1, p. 374.
2. Limestone in Trenton series, New Richmond. Wormley, analyst. Geol. Survey, Ohio, vol. 1, p. 374.
3. Limestone bed in Cincinnati series, Cincinnati. W. Simonson, analyst.
4. Limestone in Trenton series, Point Pleasant. Wormley, analyst. Geol. Survey, Ohio, vol. 1, p. 374.

CLINTON LIMESTONES.

The Clinton limestones, exposed and quarried at many points in the southwestern quarter of Ohio, are commonly fairly low in magnesia. They range from 80 to 95 per cent in lime carbonate, rarely going above the latter limit. Occasional beds are almost free from magnesium carbonate, while others may carry 10 per cent of this constituent.

Analyses of Clinton limestones, Ohio.

No.	Silica (SiO_2).	Alumina (Al_2O_3); iron oxide (Fe_2O_3).	Lime carbonate ($CaCO_3$).	Magnesium carbonate ($MgCO_3$).
1	1.30	0.55	90.03	5.71
2	2.00	1.60	93.00	3.04
3	.07	.40	95.60	3.93
4	.80	1.20	91.30	6.51
5	2.20	2.00	84.50	11.16
6	.83	.29	96.80	2.07
7	.45	.26	95.03	4.35
8	1.64	.36	97.09	.82
9	.70	.41	97.14	1.21

1. Dayton, Montgomery County.
2. Adams County.
3. New Carlisle, Miami County.
4. Smiths quarry, Ludlow Falls.
5. McDonald's quarry, Xenia, Greene County.
6. New Carlisle, Clarke County.
7. Piqua, Greene County.
8, 9. Osborn, Greene County.

Analyses 1-5 by T. G. Wormley, Rept. Geol. Survey Ohio, 1870, pp. 449-450; analyses 6-9 by N. W. Lord, Rept. Geol. Survey Ohio, vol. 6, pp. 728-729.

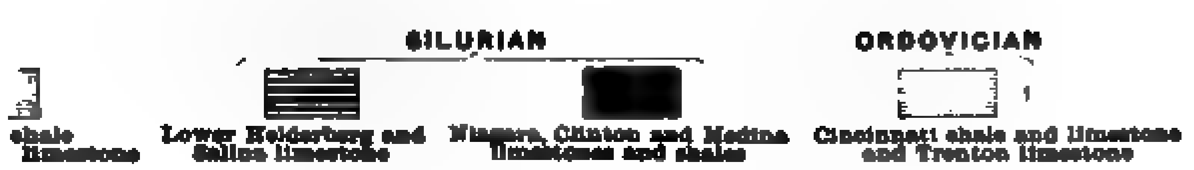
CARBONIFEROUS

Coal Measures

Mississippian limestone and sandstone

Ohio shale

H
and Oc


SILURIAN
ORDOVICIAN
shale
limestone
Lower Helderberg and
Salina limestone
Niagara, Clinton and Medina
limestones and shales
Cincinnati shale and limestone
and Trenton limestone

CORNIFEROUS LIMESTONES.

The Corniferous limestones, which correspond approximately to the Onondaga or upper Helderberg limestones of New York, contain heavy beds of magnesian limestones, with a smaller amount of limestones low in magnesia. The variation in this respect that may exist in a single quarry is well shown by the following series of analyses quoted from reports of the Ohio Geological Survey:

Variations in composition of limestone from various quarries.

No.	Silica (SiO_2).	Alumina (Al_2O_3); iron oxide (Fe_2O_3).	Lime carbonate ($CaCO_3$).	Magnesium carbonate ($MgCO_3$).
1	3.20	4.00	88.30	2.58
2	4.60	1.25	80.40	13.80
3	2.92	4.33	84.70	8.64
4	1.35	6.01	92.00	.56
5	1.57	3.05	85.55	10.39
6	1.92	1.85	74.00	21.46
7	2.20	1.97	66.15	27.97
8	1.65	2.65	72.85	22.38
9	.85	.27	97.28	2.00
10	1.49	.15	87.10	10.96
11	1.05	.20	89.16	9.48
12	1.65	.14	77.22	20.19
13	1.00	.37	89.20	9.64
14	2.65	.44	77.23	18.55
15	1.55	.18	78.60	19.79
16	2.70	3.30	65.80	27.95

Analyses 1-8 are of different beds in a quarry at Owen station, Marion County.
Analyses 9-12 are of different beds in the Kelley quarries, on Kelleys Island.
Analyses 13-16 are of beds in the Hartshorn quarries, on the Marblehead peninsula near Sandusky.

The analyses below have been selected as representing the low-magnesia beds which occur in this formation:

Analyses of Corniferous limestones, Ohio.

No.	Silica (SiO_2).	Alumina (Al_2O_3): iron oxide (Fe_2O_3).	Lime carbonate ($CaCO_3$).	Magnesium carbonate ($MgCO_3$).
1	3.20	0.80	94.80	1.21
2	....	1.74	93.21	4.70
3	4.90	.09	89.60	4.41
4	4.95	.46	90.77	3.26
5	5.40	3.80	88.40	1.96
6	16.06	2.80	72.82	5.99
7	25.00	1.20	65.80	8.02
8	1.41	2.10	93.28	2.69
9	3.20	4.00	88.30	2.58
10	1.35	6.01	92.00	.56
11	.85	.27	97.28	2.00

1. Price quarry, Columbus, Franklin County. E. Orton, analyst. Twentieth Ann. Rept. U. S. Geol. Survey, pt. 6 (continued), p. 432.
2. Casparis quarry, Columbus, Franklin County. Chemist of Cleveland Rolling Mills, analyst. Twentieth Ann. Rept. U. S. Geol. Survey, pt. 6 (continued), p. 432.
3, 4. Lilley's quarry, Columbus, Franklin County. N. W. Lord, analyst. Geol. Survey Ohio, vol. 6, p. 763.
5, 6, 7. State quarry, Columbus, Franklin County. C. C. Howard, analyst. Geol. Survey Ohio, vol. 4, p. 617.
8. Stitt quarry, Columbus, Franklin County. C. L. Mees, analyst. Geol. Survey Ohio, vol. 4, p. 936.
9, 10. Owen Station, Marion County. N. W. Lord, analyst. Geol. Survey Ohio, vol. 6, p. 769.
11. Kelley quarries, Kelleys Island. N. W. Lord, analyst. Geol. Survey Ohio, vol. 6, p. 753.

MAXVILLE (LOWER CARBONIFEROUS) LIMESTONES.

The coal fields of Ohio are encircled by a belt of Lower Carboniferous (Mississippian) rocks. Included in this series is a prominent limestone formation—the Maxville limestone. This limestone is usually low in magnesia and fairly high in lime. It will usually range from 80 to 90 per cent in lime carbonate, as shown by the analyses below.

Analyses of Maxville (lower Carboniferous) limestone, Ohio.

No.	Silica (SiO_2).	Alumina (Al_2O_3); iron oxide (Fe_2O_3).	Lime carbonate ($CaCO_3$).	Magnesium carbonate ($MgCO_3$).
1	3.02	1.60	93.08	1.59
2	5.91	2.99	89.31	1.52
3	9.01	1.18	88.71	.54
4	11.58	2.68	82.88	2.23
5	4.28	16.09	79.18	1.96

1. Glenford, Perry County.
2. Winona Furnace, Hocking County.
3, 4, 5. Webb Summit.
The analyses are taken from Rept. Geol. Survey Ohio, vol. 4, p. 934.

COAL MEASURES LIMESTONES.

Limestone beds occur at intervals throughout the Coal Measures of Ohio, as in the adjoining area of Pennsylvania. Most of these limestones are of only local importance, and require no description here. One limestone formation, however—the Ferriferous or Vanport limestone—now furnishes cement material to four Portland cement plants in Ohio and to one just across the border in Pennsylvania. It varies in thickness from 8 to 16 feet or more, and is always low in magnesia. It is usually also low in lime, ranging from 80 to 90 per cent in lime carbonate. The following analyses are representative of its composition:

Analyses of the "Ferriferous" (Coal Measures) limestone, Ohio.

No.	Silica (SiO_2).	Alumina (Al_2O_3); iron oxide (Fe_2O_3).	Lime carbonate ($CaCO_3$).	Magnesium carbonate ($MgCO_3$).
1	0.60	1.40	97.32	0.45
2	1.67	1.36	95.40	1.38
3	.86	[a] 1.66	96.18	n. d.
4	1.72	[b] 8.22	87.07	n. d.
5	3.24	2.26	93.24	2.19
6	2.90	2.71	92.02	1.85
7	1.00	1.00	94.20	.76
8	1.00	6.80	88.80	1.20
9	5.40	2.00	88.00	1.51
10	.56	[c] 1.52	97.23	.75

[a] Alumina, 0.63; iron oxide, 1.03. [b] Alumina, 1.63; iron oxide, 6.59.
[c] Alumina, 1.23; iron oxide, 0.29.

1. Elfert, Lawrence County. Twentieth Ann. Rept. U. S. Geol. Survey, pt. 6 (continued), p. 432.
2. Ironton, Lawrence County. N. W. Lord, analyst, Geol. Survey Ohio, vol. 5, p. 1109.
3, 4. Ironton, Lawrence County. C. D. Quick, analyst.
5. Lowellville, Mahoning County. N. W. Lord, analyst, Geol. Survey Ohio, vol. 5, p. 1109.
6. Holmes County. N. W. Lord, analyst, Geol. Survey Ohio, vol 5, p. 1109.
7, 8, 9. Star Furnace. T. G. Wormley, analyst, Rept. Geol. Survey Ohio, 1870, p. 450.
10. Texas Hollow. W. S. Trueblood, analyst.

QUATERNARY MARLS.

Marl deposits occur at various points in Ohio, but apparently are not so extensive as those in Indiana and Michigan. At present four plants are using marl as a Portland cement material.

PORTLAND-CEMENT INDUSTRY.

As noted above, Ohio at present ranks seventh as a producer of Portland cement. In 1904 eight Portland-cement plants were in operation in the State. Four of these, located in eastern and southeastern Ohio, employed the Ferriferous limestone with shale as raw materials;

the other four, located in central and northwestern Ohio, used a mixture of marl and clay. The limestone plants are the Diamond Portland Cement Company, of Middle Branch, Ohio; the Ironton Portland Cement Company, of Ironton, Ohio; the Alma Portland Cement Company, of Wellston, Ohio, and the Wellston Portland Cement Company, of Wellston, Ohio. All of these plants, with the possible exception of the new Alma, mix Carboniferous shales with limestone.

Analyses of limestones and shales used in Ohio.

LIMESTONES.

	1	2	3	4	5
Silica (SiO_2)	0.86	3.53	0.56	4.20	1.30
Alumina (Al_2O_3)	.63	1.14	1.23	1.61	.73
Iron oxide (Fe_2O_3)	1.03		.29	1.90	1.17
Lime (CaO)	53.86	54.45	54.45	50.66	53.34
Magnesia (MgO)	n. d.	.44	.36	.73	.75
Sulphur trioxide (SO_3)	n. d.	n. d.	tr.	.23	tr.
Carbon dioxide (CO_2)	43.20	38.74	43.17	40.60	42.72

SHALES.

	6	7	8	9	10	11
Silica (SiO_2)	60.00	55.00	60.15	62.67	63.30	69.49
Alumina (Al_2O_3)	23.26	21.79	19.78	19.99	26.00	16.42
Iron oxide (Fe_2O_3)	4.32	9.26	9.10	5.46		
Lime (CaO)	.90	n. d.	.52	1.25	1.25	2.29
Magnesia (MgO)	1.12	n. d.	.10	.72	1.25	.78
Sulphur trioxide (SO_3)	n. d.	n. d.	tr.	n. d.	n. d.	n. d.
Carbon dioxide (CO_2)	n. d.	n. d.	n. d.	n. d.	n. d.	5.43

1, 6. Ironton Portland Cement Company. C. D. Quick, analyst.
2, 11. Alma Portland Cement Company. Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 6 (continued), p. 402.
3, 10. Wellston Portland Cement Company. W. S. Trueblood, analyst.
4, 5, 7, 8, 9. Diamond Portland Cement Company. E. Davidson, analyst.

The plants using marl are the Sandusky Portland Cement Company, of Bay Bridge, Ohio; the Castalia Portland Cement Company, of Castalia, Ohio; the Buckeye Portland Cement Company, of Rushsylvania, Ohio, and the Alta Portland Cement Company, of Rushsylvania, Ohio.

Of these plants the Buckeye and Alta use marl from wet swamp deposits, while the Castalia uses marl from a deposit which is now practically dry. The Sandusky, having almost exhausted its marl deposit, is now using limestone as part of its charge and will probably soon use it entirely. The clays used at all these marl plants are obtained from Quaternary deposits in the immediate vicinity of the marl beds.

Analyses of marls and clays used in Ohio.

	Marls.		Clays.		
	1	2	3	4	5
Silica (SiO_2)	1.98	0.26	47.45	59.10	51.56
Alumina (Al_2O_3)	.97	.20	19.85	24.01	14.50
Iron oxide (Fe_2O_3)					3.84
Lime (CaO)	50.95	52.86	17.80	2.2	9.8
Magnesia (MgO)	.55	n. d.	.09	2.0	n. d.
Alkalies (K_2O, Na_2O)	.12	n. d.	4.34	n. d.	n. d.
Sulphur trioxide (SO_3)	.10	n. d.	1.03	n. d.	tr.
Carbon dioxide (CO_2)	40.03	n. d.	.57	n. d.	7.7

1, 3. Buckeye Portland Cement Company. Mineral Industry, vol. 1, p. 52.
2, 4, 5. Castalia Portland Cement Company.

PORTLAND-CEMENT RESOURCES OF OKLAHOMA.

Limestones occur in three distinct areas in Oklahoma, and are of three different geologic ages—Cretaceous, Carboniferous, and Ordovician ("Lower Silurian"). Little is on record concerning the exact distribution or composition of any of these limestones. In general, it may be said that those of Cretaceous age occur in the extreme western part of the Territory; that they are shell limestones and probably low in magnesia. The following description of the Carboniferous and Ordovician limestones is taken from a paper by Mr. C. N. Gould, published in Stone, volume 23, pages 351–354. Though containing no analyses, it indicates the general distribution and value of the limestones in question.

There are in Oklahoma two localities from which limestone for building purposes may be obtained in large quantities. The first of these is in the northeastern part of the Territory, in Kay, Noble, Payne, and Pawnee counties, and in the Osage, Kaw, Ponca, and Otoe reservations. The second locality is in the newly-opened Kiowa and Comanche Reservation, in the eastern part of Comanche County. It is the purpose of this article to discuss in some detail the rock of the two localities and to indicate briefly the logical market of the stone of each locality.

The limestone in the northeastern part of the Territory is obtained from the southern part of the Flint Hills. The Flint Hills extend practically north and south for more than 300 miles, from the Platte to the Cimarron. They are hills of erosion carved out by the action of water from the heavy limestone ledges which occur in the Upper Carboniferous and Lower Permian of the region. Much of the Kansas building stone is obtained from this range of hills. Quarries at Manhattan, Junction City, Cottonwood Falls, Florence, Winfield, and Arkansas City, Kans., as well as those near the mouth of the Platte in eastern Nebraska, are from the same general horizon.

The Arkansas River on its way from the mountains to the Mississippi strikes the Flint Hills near the Kansas-Oklahoma line. From Pueblo to Arkansas City the river flows over soft yielding rocks that have been hollowed out by water into a

broad shallow valley. At Hutchinson or Wichita, Kans., for example, there are no bluffs, and the valley is from 10 to 20 miles wide. Near Geuda Springs, Kans., the river begins to narrow rapidly. The first ledge of limestone is crossed at the dam 5 miles west of Arkansas City. Near the mouth of the Walnut, just north of the Kansas-Oklahoma line, the heavy bluffs of limestone appear, and from this point to the southeast corner of the Osage Nation the river flows in a series of ox-bow bends, seeking its tortuous way in and out among the Flint Hills. As the crow flies this distance does not exceed 80 miles, but the water of the river flows at least twice that distance. In one place two bends of the river approach within a mile and a half of each other, while to follow the channel a person would have to travel more than 9 miles. Throughout the greater part of this course the bluffs are high and precipitous. The valley is perhaps 2 miles wide on an average, nearly half of this being occupied by the sandy channel of the stream. In places, however, the distance from bluff to bluff is not more than a mile.

The smaller streams tributary to the Arkansas in this region have usually carved deep channels through the limestone ledges. These ledges follow the sinuous course of the streams, outcropping along the bluffs and forming in many places conspicuous outlines. It is from these ledges, which, as stated above, form the southern extension of the Flint Hills, that the limestone is obtained. Half a dozen or more ledges outcrop between the bed of the river and the top of the hills to the west. In the hills in the Osage and Kaw reservations east of the river there are perhaps as many more, each from 5 to 25 feet thick.

The stone is, in general, a rather fine-grained, gray, or nearly white, massive limestone. For building purposes it is easily the equal of the best stone from the Winfield or Cottonwood Falls quarries. Indeed, it will be a matter of surprise if time shall not demonstrate that the Oklahoma stone will outlast most of that obtained from Kansas. The supply is inexhaustible. Kay County alone can supply Oklahoma with building material for hundreds of years and scarcely know where it came from.

Business blocks in Newkirk, Ponca City, and Pawnee are built of stone obtained from the local quarries. These buildings rival in appearance the finest blocks built from Kansas stone. Throughout the region dressed-stone farmhouses are rapidly springing up. The stone house built by Governor William M. Jenkins while he was yet a Kay County farmer stands on his claim, 2 miles southeast of Newkirk. This is one of the first two-story stone houses ever built in "the Strip."

Dimension stone of all shapes and sizes, flagging, and rubble are obtained from the various quarries. Not long ago a block of 12 feet square and 30 inches thick was shipped. One of the most practical purposes to which the stone is being put, however, is the manufacture of stone posts. The rock splits readily into almost any required size. Advantage is taken of this fact to secure a long, slender block suitable for a fence post. Posts from 5 to 7 feet long are split down to 6 by 8 inches, and posts 15 feet long are often secured. These posts sell in the quarry for from 20 to 35 cents each, according to the size, and are rapidly replacing the wooden posts formerly used. They are very similar to the limestone posts from the Benton Cretaceous in central Kansas, and seem destined to serve as important a part in the development of the country as do the latter.

Standing upon almost any one of the high hills east of Kildare, or Newkirk, in Kay County, a person may see not only the white stone houses nestled away in the valleys or crowning the knolls, but also the lines of white posts stretching for miles across the country. It seems but a question of a few years till the greater part of the farmhouses of the county will be built of stone, and stone posts will replace the last of the wooden posts throughout the region.

The limestone of the second locality, while more restricted in area than that of the Flint Hills, is still more than sufficient to supply the southwestern part of Oklahoma

with building stone for generations. Geologically this stone is much older than that I have just discussed. In general, it belongs to the Ordovician, or even the upper Cambrian, and is thus classed among the oldest of the stratified rocks. In this region the limestone occurs as outlying hills, flanking the Wichita Mountains on the northeast and southeast.

The Wichita Mountains are nothing but the tops of buried mountain ranges sticking up out of a sea of plain. They are composed of igneous rocks, chiefly granite, gabbro, and porphyry. These, of themselves, are of course excellent building stone. At the present time these mountains are full of prospectors and miners. For seventy years reports of gold and silver have been coming from these mountains. Whether or not anything more tangible than reports will ever be obtained remains to be proven.

The Ordovician outliers trend northwest and southeast, parallel to the main range. From Fort Sill these hills extend for nearly 40 miles to the northwest, and in places are 15 miles across. Southwest of the fort the hills extend for 12 miles or more. The stone is, in general, rather coarse grained, and in places is almost marbleized. It is usually much faulted and folded, often standing on edge, showing that the region has been subjected to great pressure.

The Government buildings—barracks, officers' quarters, and stables—at Fort Sill have been constructed of limestone taken from a quarry on the reservation a mile southeast of the post. It makes a splendid building stone. The prevailing colors as seen in the building are light gray and brownish or yellowish gray. This fort, perhaps as much on account of the material composing the buildings as upon its location, seems destined to be occupied by Government troops long after all other posts in Oklahoma and the Indian Territory have been abandoned. Forts Gibson, Washita, Arbuckle, and Supply, where the buildings were principally of wood, have all been vacated by the Government, and it is unlikely that Fort Reno will long remain occupied. Fort Sill, on the contrary, will probably long remain a monument, in part—at least—to the character of the rock composing the buildings.

A word with regard to market and transportation facilities. The Flint Hills region is cut by the Santa Fe Railroad, and, for the present at least, the products of these quarries must be shipped over this road. It is the logical source of supply for such cities as Guthrie and Oklahoma City, in which at the present time there is much building being done. Unfortunately for the Oklahoma stone industry, however, there are as yet no spurs to any of the quarries in this locality. It thus happens that the stone from many of the buildings in these cities is obtained from southern Kansas, at a considerably higher cost than natural conditions warrant. Newkirk stone, however, is already on the market and the demand is steadily increasing.

In the Wichita region the Rock Island Railroad runs within less than a mile of the limestone hills. The resources of the region are as yet practically undeveloped. In time, however, this stone promises to become one of the important factors in the development of this wonderfully rich and fertile region.

PORTLAND-CEMENT RESOURCES OF OREGON.[a]

Little attention has been paid by prospectors to any of the nonmetalliferous mineral resources of Oregon except coal. In consequence, the data presented below on the distribution and composition of Oregon limestones are too scanty to be satisfactory for the purposes of

[a] For much of the data here given in regard to Oregon limestones the writer is indebted to a report by Mr. Herbert Lang, published in The Resources of the State of Oregon, a handbook issued in 1892 by the State board of agriculture. Dr. J. S. Diller has also aided him greatly by contributing data on the character and distribution of the limestones of southwestern Oregon, based on his work in that region.

the present bulletin. It is probable that workable limestone deposits, other than those described below, exist in various parts of the State. So far as known, however, the more important limestone deposits of Oregon occur in two widely separated districts—in the southwestern and the northeastern portions of the State.

MATERIALS AND CONDITIONS IN SOUTHWESTERN OREGON.

The limestones of southwestern Oregon are well developed at a number of points in Jackson and Josephine counties, and have been used to a considerable extent for lime burning and flux. These limestones are generally of uncertain age—some are Devonian, others most likely Carboniferous, and a few certainly Cretaceous. They occur as a series of lenses of greater or lesser size in the partially altered rocks of the district.

Several of these lenticular bodies of limestone outcrop in the neighborhood of Rock Point, on Rogue River, in Jackson County, and have been extensively exploited for various purposes. A small quantity has been burned locally into lime, some has been shipped to the Portland lead smelters as flux, while a larger amount has been shipped to Portland and burned there into lime. Stone for building purposes has also been derived from this series of limestone beds.

An analysis of the Rock Point limestone, made by Mr. J. S. Phillips, follows:

Analysis of limestone from Rock Point, Oreg.

Silica (SiO_2)	3.1
Iron oxide (Fe_2O_3)	2.2
Lime carbonate ($CaCO_3$)	89.4
Magnesium carbonate ($MgCO_3$)	5.3

The belt of limestone lenses extends southwest from Rock Point, with several prominent outcrops on the tributaries of Applegate, especially on Steamboat, and on Williams Creek, where the massive limestone has celebrated caverns. Similar bodies occur on Sucker Creek, southeast of Waldo, near the California line. Their distribution is extremely irregular, owing to the predominance of igneous rocks. Very large deposits are said to occur near the California line, on Williams Creek, in the extreme southeastern corner of Josephine County.

MATERIALS IN NORTHEASTERN OREGON.

Of the limestone deposits of northeastern Oregon the largest and most accessible seems to be on Burnt River, about 3 miles above Hutchinson, Baker County. The limestone beds at this point are associated with shales, and the entire series is upturned to give a steep dip. The river has cut through the beds, exposing a thickness of about 100 feet of limestone. This stone is remarkably pure, carrying usually less

than 1 per cent of silica, alumina, and iron oxide. Its quality, quantity, and proximity to the railroad and to a series of shale beds make it worth considering as a possible source of Portland-cement material.

The same series of beds outcrop in the hills to the southwest and northeast and continue into Idaho, where they form important deposits. Large limekilns are now in operation at several points on this line of outcrop.

Limestone deposits of considerable size occur in other parts of Baker County, the most important at present being one which is extensively worked for lime about 14 miles from Baker City. Other deposits occur in Grant County, and very thick and extensive beds of blue limestone are said to cover much of Union County. In Wallowa County deposits of marbles occur, which may be of service for cement.

PORTLAND-CEMENT RESOURCES OF PENNSYLVANIA.

PORTLAND-CEMENT MATERIALS.

A number of limestones suitable for use as Portland-cement materials occur in Pennsylvania, though only one of them has as yet been extensively used for this purpose. For description these limestones may be conveniently grouped as follows:

(1) Trenton limestone (Ordovician).
(2) Helderberg or Lewistown limestone (Silurian).
(3) Carboniferous limestones.

TRENTON LIMESTONE.

DISTRIBUTION.

The Trenton limestone, which furnishes the well-known "cement rock" of the Lehigh district, occurs in varying development in the counties of Northampton, Lehigh, Berks, Lebanon, Dauphin, Cumberland, Franklin, Lancaster, Center, and Blair, and to a much less extent in several other counties of southeastern Pennsylvania.

Throughout its range it is underlain by a highly magnesian (Kittatinny) limestone and overlain by a thick series of (Martinsburg and Hudson) shales and slates. Further details concerning its geologic occurrence in its most typical area will be found in the section on cement manufacture in the Lehigh district, on page 284. The distribution of the Trenton limestone in Pennsylvania is shown in a general way on Pl. XIII.

COMPOSITION.

The Trenton limestone, wherever it occurs, is almost invariably low in magnesia, and is therefore almost always an excellent Portland-cement material. At times its value as a cement material is increased

by the presence of a high percentage of clayey matter, as is well shown in the "cement rock" of the Lehigh district.

The following table of analyses shows the composition of samples of Trenton limestone from various localities in Pennsylvania. No analyses from localities in the Lehigh district are given in this table, as this district is discussed in considerable detail below (p. 284).

Analyses of Trenton limestones, Pennsylvania.[a]

	Silica (SiO_2).	Alumina (Al_2O_3), iron oxide (Fe_2O_3).	Lime carbonate ($CaCO_3$).	Magnesium carbonate ($MgCO_3$).
1	0.91	0.26	94.98	3.87
2	4.38	.64	91.89	2.88
3	5.88	1.68	90.39	2.25
4	3.62	.19	92.12	4.23
5	.54	.20	97.89	1.29
6	.39	.32	98.32	1.17
7	.82	.38	97.53	1.21
8	.76	.43	97.65	1.13
9	4.30	.36	86.13	8.86
10	2.51	.60	90.63	6.17
11	2.55	n. d.	92.00	4.54
12	8.41	.57	86.36	5.24
13	8.84	.81	89.18	.96
14	.98	.26	97.32	1.29
15	2.66	.26	95.07	1.04

[a] From Reports M1, M2, M3, Second Geol. Survey Pennsylvania A. S. McCreath, analyst.

1. Mount Etna Furnace, Blair County.
2. Rodman Furnace, Blair County.
3, 4. Tyrone, Blair County.
5, 6, 7. Shortlidge quarry, Bellefonte, Center County.
8. Campbell quarry, near Bellefonte, Center County.
9, 10. Rutherford quarry, near Harrisburg, Dauphin County.
11. Cumbler quarry, near Harrisburg, Dauphin County.
12. Craighead quarry, Mount Holly, Cumberland County.
13. Mont Alto, Franklin County.
14. Williamson, Franklin County.
15. Rauchs Gap, Clinton County.

HELDERBERG OR LEWISTOWN LIMESTONE.

DISTRIBUTION.

The Helderberg limestone outcrops in central and eastern Pennsylvania in a series of narrow bands whose distribution is too complicated to be readily described, but is shown on Pl. XIII.

COMPOSITION.

Analyses of Helderberg limestone, Pennsylvania.[a]

No.	Silica (SiO_2).	Alumina (Al_2O_3); Iron oxide (Fe_2O_3).	Lime carbonate ($CaCO_3$).	Magnesium carbonate ($MgCO_3$).	Sulphur (S).
1	2.50	0.84	95.66	1.55	0.10
2	3.00	.64	95.09	1.58	.03
3	3.02	.57	95.57	1.52	.03
4	1.80	.80	95.25	2.27	.05
5	1.62	.65	96.16	1.59	.07
6	10.85	.58	84.78	3.86	.05
7	1.69	.44	96.14	1.60	.05
8	5.70	1.77	90.90	2.16	.08
9	2.33	.70	94.03	1.97	.06
10	5.04	1.14	91.12	1.57	.03
11	5.30	1.78	89.29	2.56	.06
12	49.03	1.67	47.30	2.01	.15
13	21.68	4.66	70.59	1.74	.03
14	15.72	2.55	71.73	7.62	n. d.
15	6.53	1.21	89.64	1.82	n. d.
16	2.85	.70	94.28	1.53	.06
17	7.86	2.11	87.93	1.94	.23
18	11.93	1.36	82.73	2.83	.70
19	4.25	.84	93.27	1.38	.11
20	3.92	.68	93.87	1.31	.15
21	7.65	.71	88.82	2.34	.21
22	3.02	.54	94.28	2.12	.21
23	4.26	1.10	92.20	2.17	.15
24	20.24	2.97	73.43	2.65	n. d.
25	3.61	1.11	90.18	4.31	.25
26	5.94	1.26	89.39	3.25	.27

[a] From Reports M1, M2, M3, Second Geol. Survey Pennsylvania. A. S. McCreath, analyst.

1, 2, 3. Baker quarry, Altoona, Blair County.
4. Creswell quarry, Hollidaysburg, Blair County.
5. Manning quarry, Hollidaysburg, Blair County.
6. Loop quarry, Hollidaysburg, Blair County.
7. Sarah furnace, Blair County.
8, 9, 10. Hudson quarry, Three Springs, Huntingdon County.
11, 12. McCarthy quarry, Saltillo, Huntingdon County.
13. Jersey Shore, Lycoming County.
14, 15. Still quarry, 2 miles northeast Montebello Narrows, Perry County.
16–17. Bossardville, Hamilton Township, Monroe County.
18–21. Van Auken quarry, Middle Smithfield Township, Monroe County.
22–23. Brown quarry, Smithfield Township, Monroe County.
24. Experiment Mills quarry, near Delaware Water Gap, Monroe County.
25–26. Poxono Island, Monroe County.

A deposit of limestone near Kings Rock, on Susquehanna River in Lycoming County, belonging to this series, is described by Mr. Uriah Cummings in the Seventeenth Annual Report of the United States Geological Survey, part 3, pages 889–890. He states that

a natural cement of the following composition had been made from this rock:

Analysis of natural cement, Kings Rock, Pa.

Silica (SiO_2)	28.14
Alumina (Al_2O_3)	9.10
Iron oxide (FeO)	3.20
Lime (CaO)	53.34
Magnesia (MgO)	1.00
Alkalies (K_2O, Na_2O)	2.80
Water and loss	2.40

Such an analysis of a natural cement would imply that the rock from which it was made was closely similar in composition to the cement rock of the Lehigh district, and that the addition of 10 per cent or so of pure limestone would give a good Portland cement.

CARBONIFEROUS LIMESTONES.

DISTRIBUTION.

Names and stratigraphic position of Carboniferous limestones, Pennsylvania.

Geologic group.	Name of limestone.	Thickness.	Stratigraphic position.
		Feet.	
Dunkard formation or Upper Barren measures.	Upper Washington limestone.	30	At top of Washington formation, 250 to 425 feet above the Waynesburg coal.
Monongahela formation or Upper Productive Measures.	Waynesburg limestone	35	20 feet below the Waynesburg coal.
	Benwood or Great limestone.	73	120 feet above the Pittsburg coal.
	Sewickley or Fishpot limestone.	30	100 feet or more above the Pittsburg coal.
	Redstone limestone	10	60 to 100 feet above the Pittsburg coal.
Conemaugh formation or Lower Barren measures.	Pittsburg limestone	12	20 feet below the Pittsburg coal.
	Elk Lick limestone	6	Between Pittsburg and Upper Freeport coal.
	Ames or Crinoidal limestone.	8	Do.
Allegheny formation or Lower Productive measures.	Upper Freeport limestone.	28	Below Upper Freeport coal.
	Lower Freeport limestone.	5	Below the Lower Freeport coal.
	Johnstown limestone	10	Below the Upper Kittanning coal.
	Vanport or Ferriferous limestone.	20	Below the Lower Kittanning coal.
Pottsville formation	Upper Mercer limestone	4	
	Lower Mercer limestone	3	
Mauch Chunk formation.	Greenbrier or Mountain limestone.	30	
Pocono formation	Siliceous limestone	60	
	Benezette limestone	7	

COMPOSITION.

Analyses of Ferriferous or Vanport limestone, Pennsylvania.[a]

No.	Silica (SiO_2).	Alumina (Al_2O_3); Iron oxide (Fe_2O_3).	Lime carbonate ($CaCO_3$).	Magnesium carbonate ($MgCO_3$).
1	2.03	1.29	95.53	0.91
2	.79	1.46	96.01	1.50
3	2.30	1.38	94.72	1.04
4	2.11	.93	95.57	1.42
5	2.10	2.09	94.18	1.48
6	3.42	1.67	93.25	1.74
7	3.22	1.71	93.29	.97
8	2.19	1.31	95.23	.41
9	1.96	1.05	95.53	.93
10	1.78	1.53	95.20	1.27
11	1.11	.87	96.43	1.20
12	1.91	1.31	94.39	1.70
13	2.04	1.31	93.64	1.82
14	1.30	.99	96.43	.91
15	1.28	.78	96.58	.83
16	2.39	2.20	86.91	6.66
17	7.37	2.61	86.21	1.78
18	3.37	1.71	91.78	1.81
19	1.63	1.64	94.36	1.63
20	2.20	1.63	94.11	1.37
21	2.79	.80	94.21	1.73
22	1.97	.63	95.77	1.10
23	3.07	1.56	93.34	1.46
24	2.08	1.19	94.78	1.37
25	2.09	2.03	92.86	1.59
26	.37	1.00	96.78	1.28
27	2.77	1.82	93.48	1.54
28	7.03	2.32	88.46	1.44
29	4.78	1.29	91.61	1.57
30	4.80	1.59	91.09	1.59

[a] From Reports M, M2, M3, Second Geol. Survey Pennsylvania. A. S. McCreath, analyst.

1, 2. Stewardson Furnace, Madison Township, Armstrong County.
3. Colwell quarry, near Mahoning Furnace, Armstrong County.
4. Reynolds quarry, near Kittanning, Armstrong County.
5. George quarry, near South Bend, Armstrong County.
6. Rhea quarry, near Greendale, Armstrong County.
7. Graff quarry, near Buffalo mills, Armstrong County.
8. Long Run, Porter Township, Clarion County.
9. Hindman quarry, Clarion Township, Clarion County.
10. Sligo Furnace, Piney Township, Clarion County.
11. Barger quarry, Perry Township, Clarion County.
12. Bovaird quarry, near Brockwayville, Jefferson County.
13. Hanna quarry, near Sprankle's Mills, Jefferson County.
14. Enty quarry, near Worthville, Jefferson County.
15. Shields quarry, near Dowlingville, Jefferson County.
16. Winslow property, near Benezette, Elk County.
17. Toby Creek, Fox Township, Elk County.
18. Brandy Camp post-office, Horton Township, Elk County.
19, 20. Kane quarry, near Wilcox, Jones Township, Elk County.
21. Shinn quarry, Wampum, Lawrence County.
22. McCord quarry, Mount Jackson, Lawrence County.
23. Johnson quarry, Newcastle, Lawrence County.
24. Moffit quarry, Croton, Lawrence County.
25. Simpson quarry, Richmond, Indiana County.
26. Pine Creek Furnace quarry, Kittanning, Armstrong County.
27. Severn quarry, near Vanport, Beaver County.
28, 29. Powers quarry, near Vanport, Beaver County.
30. Tygart's quarry, near Vanport, Beaver County.

PORTLAND-CEMENT INDUSTRY IN PENNSYLVANIA.

The State of Pennsylvania now produces about half of the total United States output of Portland cement. This enormous production, amounting to about 10,000,000 barrels annually, comes almost entirely from plants located in the so-called Lehigh district, in Berks, Lehigh, and Northampton counties. Seventeen plants are located in the Pennsylvania portion of this important district, while the two remaining Portland-cement plants in Pennsylvania are located in the extreme western part of the State.

The following list of Portland-cement plants operating in Pennsylvania in 1904 has been corrected by Mr. R. W. Lesley, president of the American Cement Company, to whom the writer's acknowledgments are due for this and other courtesies.

Name and location of Portland-cement plants in Pennsylvania, 1904.

American Cement Company of Pennsylvania	Egypt.
Atlas Portland Cement Company	Northampton and Coplay.
Bath Portland Cement Company	Bath.
Bonneville Portland Cement Company	Siegfried.
Central Cement Company[a]	Egypt.
Clinton Cement Company	Pittsburg.
Coplay Cement Manufacturing Company	Coplay.
Crescent Portland Cement Company	Wampum.
Dexter Portland Cement Company	Nazareth.
Lawrence Cement Company of Pennsylvania	Siegfried.
Lehigh Portland Cement Company	Ormrod, West Coplay.
Martins Creek Portland Cement Company[b]	Martins Creek.
Nazareth Cement Company	Nazareth.
Northampton Portland Cement Company	Stockertown.
Penn-Allen Portland Cement Company	Penn-Allen.
Pennsylvania Cement Company	Bath.
Phoenix Cement Company	Nazareth.
Reading Cement Company	Molltown.
Whitehall Portland Cement Company	Cementon.

In describing the Portland-cement industry of the State, the Lehigh district will first be discussed in considerable detail, after which the isolated plants in western Pennsylvania will be briefly described (p. 294).

LEHIGH DISTRICT.

The following description of the cement-rock deposits and cement industry in the Lehigh district is based largely upon field work by the writer during the early summer of 1903. Acknowledgments are due to the managers and chemists of various cement plants in the Lehigh district, who have aided the writer greatly in this work. Use has also

[a] Owned by same interest as American Cement Company of Pennsylvania.
[b] Owned by same interest as Alpha Portland Cement Company. (See New Jersey, p. 243.)

been made of the report by Professor Kümmel, on the Portland-cement industry in New Jersey,[a] and of an unpublished report by Prof. T. N. Dale, on the geology of the Slatington quadrangle.

GEOLOGY.

The "Lehigh district" of the engineer and cement manufacturer has been so greatly extended in recent years that the name is now hardly applicable. Originally it included merely one small area about 4 miles square, located along Lehigh River, partly in Lehigh County and partly in Northampton County, containing the villages of Egypt, Coplay, Northampton, Whitehall, and Siegfried. The cement plants which were located here at an early date secured control of most of the cement-rock deposits in the vicinity, and plants of later establishment have therefore been forced to locate farther and farther away from the original center of the district. At present the district includes parts of Berks, Lehigh, and Northampton counties, Pa., and Warren County, N. J., reaching from near Reading, Pa., at the southwest, to a point a few miles north of Stewartsville, N. J., at the northeast. It forms, therefore, an oblong area about 25 miles long from southwest to northeast and about 4 miles wide. Within this area twenty Portland-cement plants are now in operation, and the Portland cement produced in this relatively small district amounts to almost two-thirds of the entire United States output.

Within the "Lehigh district," as above defined, three geologic formations occur, all of which must be considered in attempting to account for the distribution of the cement materials used there. These formations, named in descending order, are (1) Hudson shales, slates, and sandstones; (2) Trenton limestone (Lehigh cement rock); (3) Kittatinny limestone (magnesian). As all these rocks dip, in general, northwestward, the Hudson shales occupy the northwestern portion of the district, while the Trenton cement rock and magnesian Kittatinny limestone outcrop in succession farther southeast.

MAGNESIAN KITTATINNY LIMESTONE.

Underneath the cement-rock series lies a very thick formation consisting of light-gray to light-blue massive-bedded limestone, with frequent beds of chert. These Kittatinny limestones are predominantly highly magnesian, though occasionally beds of pure nonmagnesian limestone will be found in the series. The magnesian beds are, of course, valueless for Portland-cement manufacture, but the pure limestone beds furnish part of the limestone used in the Lehigh district for addition to the cement rock. An excellent example of this is furnished by the quarry near the east bank of Lehigh River,

[a] Ann. Rept. New Jersey State Geologist, 1900, pp. 9-101.

just above Catasauqua. In this quarry most of the beds are highly magnesian, and are therefore useful only for road metal and flux; but a few pure limestone beds occur, and the material from these low-magnesia beds is shipped to a neighboring cement mill.

Numerous analyses of the highly magnesian limestones are available, from which a few typical results have been selected for insertion here. Analyses of the purer limestone, used to add to the cement rock, will be found in table on page 289.

Analyses of magnesian Kittatinny limestone.

	1	2	3	4	5	6	7	8	9	10
Silica (SiO_2)	9.9	9.9	8.8	5.5	9.8	4.9	2.0	8.0	4.1	16.9
Alumina (Al_2O_3) Iron oxide (Fe_2O_3)	1.7	1.7	.8	1.3	3.7	6.5	8.4	5.3	1.6	1.0
Lime (CaO)	27.6	28.5	29.4	28.2	26.4	27.3	32.4	26.3	30.3	28.3
Magnesia (MgO)	17.9	17.3	17.8	20.2	15.1	14.6	15.5	17.4	18.3	15.3
Carbon dioxide (CO_2)	41.9	41.5	42.8	44.3	45.0	44.8	42.5	41.1	44.1	38.9

1. Chandlers Island, Sussex County, N. J.
2. Sparta, Sussex County, N. J.
3. Asbury, Warren County, N. J.
4. Oxford Furnace, Sussex County, N. J.
5, 6. Clinton, Hunterdon County, N. J.
7. Pottersville, Somerset County, N. J.
8, 9. Peapack, N. J.
10. Annandale, N. J.

While all of the above analyses are from New Jersey localities the magnesian limestone of the rest of the Lehigh district would give closely similar results.

TRENTON LIMESTONE.

The Lehigh cement rocks, which are approximately equivalent in age to the lowest Trenton beds of New York, are made up of a series of more or less argillaceous limestones. The formation appears to vary in thickness from 150 feet in New Jersey to 250 feet or even more at Nazareth and on Lehigh River. Its upper beds, near the contact with the overlying Hudson shales, are very shaly or slaty black limestones, carrying approximately 50 to 60 per cent of lime carbonate and 40 to 50 per cent of silica, alumina, iron, etc. Lower in the formation the percentage of lime steadily increases, while that of clayey material decreases correspondingly, until near the base of the formation the rock may carry from 85 to 95 per cent of lime carbonate with only 5 to 15 per cent of impurities. This change in chemical composition is accompanied by a change in the appearance and physical character of the rock, which gradually loses its slaty fracture and blackish color as the percentage of lime increases, until near the

base of the formation it is often a fairly massively bedded dark-gray limestone. Even so, it can usually be readily distinguished from the magnesian Kittatinny limestone, described below, for the cement rock is always darker than the magnesian limestone and contains none of the chert beds which are so common in the magnesian rock.

The Lehigh cement rock is never nearly so high in magnesia as is the underlying Kittatinny limestone. It does, however, carry considerable magnesia (as compared with other Portland-cement materials) throughout its entire thickness, and few analyses will show less than 4 to 6 per cent of magnesium carbonate. The following series of analyses is fairly representative of the lower, middle, and upper beds of the formation. The specimens from the upper beds, near the Hudson shales, show considerably less lime and more clayey matter than those from the lower parts of the formation.

Analyses of Trenton limestone (Lehigh cement rock).[a]

	1	2	3	4	5	6	7	8	9	10
Silica (SiO_2)	1.86	5.03	8.38	11.90	11.71	11.11	17.04	22.71	19.53	24.45
Alumina (Al_2O_3)	.60	2.06	4.03	4.42	4.36	4.40	6.90	5.84	6.03	5.68
Iron oxide (Fe_2O_3)	.51	1.23	1.32	1.70	1.62	1.91	2.13	2.13	1.70	1.57
Lime (CaO)	53.64	49.73	45.45	44.18	43.47	42.51	37.53	36.50	35.71	35.00
Magnesia (MgO)	.81	1.02	1.34	1.18	1.82	2.89	2.17	1.69	3.33	2.21
Carbon dioxide (CO_2)	43.03	40.19	37.18	36.01	36.15	36.57	32.88	30.52	32.73	29.89

[a] Ann. Rept. New Jersey State Geologist, 1900, p. 95.

The specimens whose analyses are given above were mostly from the vicinity of Belvidere, N. J., and, though representative in other respects, seem to have been rather lower in magnesia than the usual run of the Trenton limestone in the Lehigh district.

HUDSON SHALES.

This series includes very thick beds of dark-gray to black shales, with occasional thin beds of sandstone. In certain localities, as near Slatington and Bangor, Pa., and Newton, N. J., these shales have been so altered by pressure as to become slates, the quarrying of which now supports a large roofing-slate industry.

The geographic distribution of the Hudson shales and slates in the Lehigh district can be indicated only approximately without the presentation of a geologic map of the area. It may be said that they cover practically all of Northampton, Lehigh, and Berks counties north of a line passing through Martins Creek, Nazareth, Bath, Whitehall, Ironton, Guthsville, Monterey, Kutztown, Molltown, and Leesport.

The composition of the typical shales and slates of the upper part of the Hudson formation is well shown by the following analyses:

Analyses of Hudson shales and slates in Pennsylvania and New Jersey.

	1	2	3	4
Silica (SiO_2)	68.62	68.00	56.60	[a] 76.22
Alumina (Al_2O_3)	12.68	14.40	21.00	13.05
Iron oxide (Fe_2O_3)	4.20	5.40	5.65	
Lime (CaO)	1.31	2.68	3.42	2.67
Magnesia (MgO)	1.79	1.51	2.30	.93
Alkalies	3.73	.11	.50	n. d.
Carbon dioxide (CO_2)	3.00	2.30	2.20	n. d.
Water (H_2O)	4.47	2.70	3.00	n. d.

[a] Insoluble.

1. East Bangor, Pa. Twentieth Ann. Rept. U. S. Geol. Survey, pt. 6, p. 436.
2. 1 mile northwest Colemanville, N. J. Geology New Jersey, 1868, p. 136.
3. Delaware Water Gap, N. J. Geology New Jersey, 1868, p. 136.
4. Lafayette, N. J. Rept. New Jersey State Geol. for 1900, p. 74.

As above noted, the rocks of the Lehigh district have a general dip to the northwest, though there are numerous local exceptions to this rule. The lowest beds of the Hudson series, therefore, are those which outcrop along the southern boundary of the formation, as above outlined. These lowest beds carry much more lime and less silica, alumina, and iron than the higher beds whose analyses are given above. The lowest beds of the Hudson shales become more calcareous and form a natural transition into the underlying cement rock or Trenton limestone.

MANUFACTURING METHODS.

COMBINATION OF MATERIALS USED.

Throughout most of the Lehigh district the practice is to mix with a relatively large amount of the "cement rock" or argillaceous limestone a small amount of pure limestone, in order to bring the lime carbonate content up to the percentage proper for a Portland-cement mixture. As above noted, all of the "cement rock" is derived from the middle part of the Trenton formation, where the beds will run from 60 to 70 per cent of lime carbonate. The pure limestone which is required to bring this material up to the necessary percentage of lime carbonate (about 75 per cent) is obtained either from the lower portion of the Trenton itself or from certain low-magnesian beds occurring in the Kittatinny formation.

In the plants located near Bath and Nazareth, however, the practice has been slightly different. In this particular area the cement-rock

quarries usually show rock carrying from 70 to 80 per cent of lime carbonate. The mills in this vicinity, therefore, require practically no pure limestone, as the quarry rock itself is sufficiently high in lime carbonate for the purpose. Indeed, it is at times necessary for these plants to add clay or slate instead of limestone to their cement rock in order to reduce its content of lime carbonate to the required figure. In general, however, it may be said that Lehigh practice is to mix a low-carbonate cement rock with a relatively small amount of pure limestone, and analyses of both these materials, as used at various plants in the district, are given below.

Analyses of materials used in the Lehigh district.

	Cement rock.								Pure limestone.		
Silica (SiO_2)	15.06	19.06	19.08	22.22	13.80	9.52	19.62	14.20	2.14	3.02	1.98
Alumina (Al_2O_3)	9.02	4.44	7.92	7.24	6.08	4.72	5.68	6.14	1.46	1.90	.70
Iron oxide (Fe_2O_3)	1.27	1.14		.92							
Lime carbonate ($CaCO_3$)	70.10	69.24	67.07	63.45	76.08	80.71	69.78	74.30	94.35	92.05	95.19
Magnesium carbonate ($MgCO_3$)	3.96	4.21	4.06	4.56	4.51	4.92	4.90	3.24	2.18	3.04	2.08

CHARACTER AND COMPOSITION OF THE CEMENT ROCK.

The cement rock is a dark-gray to black slaty limestone, breaking with an even fracture into flat pieces, which usually have smooth, glistening surfaces. As the percentage of lime carbonate in the rock increases—i. e., as the lower beds of the formation are reached—the color becomes a somewhat lighter gray, and the surfaces of the fragments lose their slaty appearance.

The range in composition of the cement rock as used at various plants is well shown in the first eight columns of the above table. The nearer the material from any given quarry or part of a quarry approaches the proper Portland-cement composition (say 75 to 77 per cent lime carbonate) the less addition of pure limestone will be necessary. In by far the greater part of the district, as above noted, the cement rock is apt to run about 65 to 70 per cent of lime carbonate, therefore requiring the addition of a proportionate amount of limestone. Most of the quarries near Bath and Nazareth, however, have been opened on beds of cement rock running considerably higher in lime carbonate, and occasionally running so high (80 per cent, etc.) as to require the addition of shale or clay rather than of pure limestone.

CHARACTER AND COMPOSITION OF THE PURE LIMESTONES.

The pure limestones added to the cement rock are commonly gray, and break into rather cubical fragments. The fracture surfaces show

a finely granular structure, quite distinct in appearance from the slaty cement rock.

In composition the limestones commonly used will carry from 90 to 96 per cent of lime carbonate, with rather less magnesium carbonate than is found in the cement rock. All of the cement plants own and operate their own cement-rock quarries, but most of them are compelled to buy the pure limestone. When this is the case only very pure grades of limestone are purchased, but when a cement plant owns its limestone quarry material running as low as 85 per cent of lime carbonate is often used.

QUARRY PRACTICE.

In most of the cement-rock quarries of the Lehigh district the rock dips from from 15° to 25°, usually to the northwest. At a few quarries, particularly in New Jersey, the dip is much steeper. The quarries are opened, preferably, on a side hill, and the overlying stripping, which consists of soil and weathered rock, is removed by scrapers or shoveling. The quarry of the Lawrence Cement Company has been extended in its lower levels so as to give a tunnel through which the material is hoisted to the mill. Several other quarries have been carried straight down, until now they are narrow and deep pits, from which the material is hoisted vertically. The Bonneville Portland Cement Company quarry is an extreme example of this type.

In quarries opened on a side hill, so as to have a long and rather low working face and a floor at the natural ground level, the rock is commonly blasted down in benches, sledged to convenient size for handling and crushing, and carried by horse carts to a point in the quarry, some distance from the face, where the material can be dumped into cars, which are hauled by cable to the mill. Occasionally the material is loaded at the face into small cars running on temporary tracks. The loaded cars are then drawn by horses or pushed by men to a turntable, where they are connected to the cable and hauled to the mill. While these methods seem clumsy at first sight, they are capable of little improvement. The amount of rock used every day in a large mill necessitates very heavy blasting, and this prevents permanent tracks and cableways from being laid near to the working face.

At several quarries the loading into the cars or carts is accomplished by means of steam shovels. The cement rock seems to be well adapted for handling by steam shovels, but even then much sledging is necessary, and the blasting operations are interfered with.

MILL PRACTICE.

What may be considered as typical American practice in the manufacture of Portland cement from dry materials owes its present success largely to the works of the Lehigh district. Previous to the

commencement of Portland-cement manufacture in Pennsylvania, dry processes had not been looked upon with favor. The European plants then in existence used wet processes exclusively, differing only in the amount of water that was used.

A dry process can not well be used in stationary kilns, whether of dome or chamber type, for even if the mixing be done dry it will be necessary to add water in making the mixture into bricks. The natural result was that these early plants used water very liberally—almost as freely as the Michigan marl plants of to-day, and with far more excuse for doing so.

With the introduction of the rotary kiln a dry process became not only possible but advisable, and the Lehigh practice of to-day is the result. The usual Lehigh practice may be summed up as follows:

The cement rock is crushed and dried, the first of these operations often taking place in the quarry. Large gyratory crushers are commonly used for this work, while the drying is usually done in rotary driers. The necessary amount of limestone, also previously crushed and dried, is added, and the two materials are mixed and further reduced together. Occasionally a smaller gyratory crusher, breaking to say one-half inch, is the next step in the process of reduction. Commonly, however, the mixture goes to ball mills, comminuters or Williams mills, and then to tube mills. Some of the plants use Griffin mills in place of those noted, while the Atlas plant uses the Huntingdon mill.

The raw mixture is ground to a fineness usually not exceeding 85 per cent through a 100-mesh sieve, and often falling much lower. Compared with the practice at plants using limestone-clay mixtures, this is coarse work. It is less harmful than might be expected, however, owing to the fact that most of the mixture is made up of cement rock which is already naturally well mixed.

The mixture is usually dampened (to prevent too much of it being blown out of the kiln) and fed to rotary kilns. Except at the new Edison plant at Stewartsville, these kilns are commonly 6 feet in diameter and 60 to 110 feet in length.

CHARACTER AND COMPOSITION OF THE PRODUCT.

The analyses given in the following table will serve to show the composition of the product of the Lehigh district. Of the 10 analyses quoted, those numbered 1 to 8, inclusive, are fairly representative cements. Analyses 9 and 10, on the other hand, are of a brand carrying a very low content of alumina and iron oxide and a correspondingly high percentage of silica.

Analyses of Lehigh district cements.

	1	2	3	4	5	6	7	8	9	10
Silica (SiO_2)	21.30	21.96	21.1	20.87	19.06	21.65	22.68	21.08	24.23	24.48
Alumina (Al_2O_3)	7.65	8.29	8.0	7.60	7.47	8.09	6.71	7.86	4.80	4.51
Iron oxide (Fe_2O_3)	2.85	2.67	2.5	2.66	2.29	2.93	2.35	2.48	1.86	2.68
Lime (CaO)	60.95	60.52	65.6	63.04	61.23	63.10	62.30	63.68	63.01	64.33
Magnesia (MgO)	2.95	3.43	2.4	2.80	2.83	2.00	3.41	2.62	3.20	2.59
Alkalies (K_2O, Na_2O)	1.15	(a)	(a)	(a)	1.41	(a)	(a)	(a)	(a)	(a)
Sulphur trioxide (SO_3)	1.81	1.49	(a)	1.50	1.34	1.02	1.88	1.25	1.20	1.41

a Not determined.

The characteristics of the Lehigh district Portland cements are best brought out by the following summary of the range and average of the various constituents. In making up the average the silica, alumina, and iron oxide contents of analyses Nos. 9 and 10 have not been used, and the lime percentage of No. 3 has also been excluded. For comparison, 9 and 10 have been averaged for the first three constituents, and the results are placed in the fourth column.

Range and average of Lehigh district Portland cement.

	Maximum.	Average.	Minimum.	Average of 9 and 10.
Silica (SiO_2)	22.68	21.21	19.06	24.355
Alumina (Al_2O_3)	8.29	7.71	6.71	4.565
Iron oxide (Fe_2O_3)	2.93	2.59	2.29	2.270
Lime (CaO)	64.33	62.46	60.52	....
Magnesia (MgO)	3.43	2.82	2.00	....
Alkalies (Na_2O, K_2O)	1.41	1.28	1.15	....
Sulphur trioxide (SO_3)	1.88	1.43	1.02	....

Portland cement production of the Lehigh district, 1890–1902.

Year.	Lehigh district.		Entire United States.			Percentage of total product manufactured in Lehigh district.
	Number of plants.	Number of barrels.	Number of plants.	Number of barrels.	Value.	
1890	5	201,000	16	335,500	$439,050	60.0
1891	5	248,500	17	454,813	1,067,429	54.7
1892	5	280,840	16	547,440	1,152,600	51.3
1893	5	265,317	19	590,652	1,158,138	44.9
1894	7	485,329	24	798,757	1,383,473	60.8
1895	8	634,276	22	990,324	1,586,830	64.0
1896	8	1,048,154	26	1,543,023	2,424,011	68.1
1897	8	2,002,059	29	2,677,775	4,315,891	74.8
1898	9	2,674,304	31	3,692,284	5,970,773	72.4
1899	11	4,110,132	36	5,652,266	8,074,371	72.7
1900	15	6,153,629	50	8,482,020	9,280,525	72.6
1901	16	8,595,340	56	12,711,225	12,532,360	67.7
1902	17	10,829,922	65	17,230,644	20,864,078	62.8
1903 [a]	17	11,400,000	68	19,000,000	....	60.0

[a] Estimated.

FUTURE EXTENSIONS.

As noted in the earlier portion of this paper, the cement deposits have been developed only from near Reading, Pa., to a point a few miles from Stewartsville, N. J. Most of the readily accessible cement land between these points has been taken up by the cement companies or is being held at impossible prices by the owners. Under these circumstances it seems probable that few additional plants can be profitably established in the district now developed, and that the growth of the industry here will be brought about by extending the district. A few notes on the distribution of the same cement beds in adjoining areas may therefore be of interest to those desiring to engage in the manufacture of Portland cement from materials of the Lehigh district type.

Northeast of Stewartsville, N. J., the cement beds outcrop at frequent intervals in the Kittatinny Valley all the way across New Jersey, and a few miles into Orange County, N. Y. The exact locations of these deposits, with numerous analyses of the cement rocks, are given in the Annual Report of the State Geologist of New Jersey for 1900, pages 41–95. Many detailed maps in that report show the outcrops very precisely.

Southwest of Reading the Trenton beds outcrop in a belt that crosses Lebanon, Cumberland, and Franklin counties, Pa., passing

near the towns of Lebanon, Harrisburg, Carlisle, and Chambersburg. In Maryland the Trenton rocks occur in Washington County, while in West Virginia and Virginia they are extensively developed.

Throughout this southern extension of the Lehigh rocks the Trenton is not everywhere an argillaceous limestone, but it is frequently so, and it is always very low in magnesium carbonate. It is therefore probably safe to say that in southern Pennsylvania, Maryland, West Virginia, and Virginia the Trenton rocks are everywhere good Portland-cement materials, though in some places they will require pure limestone, and in other places clay, to bring them to proper composition.

WESTERN PENNSYLVANIA.

Two small Portland cement plants are in operation in western Pennsylvania, each of which presents certain features of interest.

The Portland cement plant of the Clinton Iron and Steel Company, located at Pittsburg, was the first plant to utilize a mixture of blast-furnace slag and limestone in the manufacture of a true Portland cement, having commenced this industry several years before it was taken up by the Illinois Steel Company at Chicago.

The Crescent Portland Cement Company, located at Wampum, Lawrence County, is one of the oldest Portland cement plants in the United States, having gone into operation when the Saylors were the only operators in the Lehigh district. The material used here is the Ferriferous (Vanport) limestone, of Carboniferous age, and a shale overlying this limestone.

Analyses of Portland cement materials, Wampum, Pa.

	Limestone.	Shale.
Silica (SiO_2)	5.52	65.99
Alumina (Al_2O_3)	2.97	21.57
Iron oxide (Fe_2O_3)		6.07
Lime (CaO)	49.66	.47
Magnesia (MgO)	.78	.82
Carbon dioxide (CO_2)	n. d.	n. d.

PORTLAND-CEMENT RESOURCES OF RHODE ISLAND.

The only limestone beds in this State large enough to be of economic importance occur on the Lime Rocks, two small islets lying between Newport and Fort Adams. The limestones occurring at this locality have been rather doubtfully referred to the Cambrian in the latest discussion[a] of Rhode Island geology. Though commonly referred to as

[a] Foerste, A. F., Geology of the Narragansett Basin, Mon. U. S. Geol. Survey, vol. 33, p. 318, 1899.

dolomite the Lime Rock stone is not a very highly magnesian rock, as is shown by the following analysis[a] by J. H. Appleton of a specimen from the Harris quarry.

Analysis of Rhode Island limestone.

Silica (SiO_2)	2.748
Alumina (Al_2O_3)	.309
Iron oxide (Fe_2O_3)	.011
Lime carbonate ($CaCO_3$)	88.23
Magnesium carbonate ($MgCO_3$)	8.80
Moisture	.04

This rock carries too much magnesia to permit its use in Portland-cement manufacture under the present standards, and its amount and location with respect to fuel and market are not particularly advantageous.

Small beds of limestone occur at other localities in the State, but none of these are of sufficient extent to be workable, whatever may be their chemical composition.

PORTLAND CEMENT RESOURCES OF SOUTH CAROLINA.

Limestones occur at many points in South Carolina, but no good geological map of the State is in existence and no recent report has been issued on these rocks. The analyses given below are, with one exception, very old, but they will give some idea of the composition and location of the limestones.

The western portion of the State contains a number of beds of metamorphosed limestone or marble that seem to be satisfactory in composition, but fuel supply, local markets, and cheap transportation are all lacking.

Analyses of metamorphic limestones, western South Carolina.

	1	2	3	4	5	6	7
Silica (SiO_2)	25.0		16.0	10.0	11.0		6.40
Alumina (Al_2O_3)	5.0	7.00	9.0	4.50	2.5	13.5	......
Iron oxide (Fe_2O_3)							3.14
Lime carbonate ($CaCO_3$)	70.0	92.00	75.0	85.00	86.0	86.0	90.56
Magnesium carbonate ($MgCO_3$)	......	1.00	Tr.	.50	.5	.5	Tr.

1. Brasstown Creek, Pickens district.
2. Saluda River, Laurens district.
3. Highest limestone bed, York.
4. Lower limestone bed, York.
5. Hardin's limestone bed, York.
6. Garlington's quarry, Laurens district.
7. Limestone Springs, Spartanburg.

Analyses by Tuomey, Rept. Geol. South Carolina, 1848, pp. 262-261.

[a] Twentieth Ann. Rept. U. S. Geol. Survey, pt. 6, p. 442.

In the Coastal Plain soft limestones of Tertiary age, the so-called "marls," outcrop at many points. Much of these materials would be very satisfactory for Portland cement manufacture.

Analyses of Tertiary limestones, eastern South Carolina.

	1	2	3	4	5
Silica (SiO_2)	12.90	16.20	16.00	18.60	10.20
Alumina (Al_2O_3)	7.02	Tr.	4.75	.40	1.00
Iron oxide (Fe_2O_3)		Tr.	Tr.	Tr.	Tr.
Lime carbonate ($CaCO_3$)	78.52	76.88	63.50	68.00	66.04
Magnesium carbonate ($MgCO_3$)	.15	1.41	7.00	1.20	2.56

1. Strawberry station, Berkeley County.
2. Elwood plantation, Cooper River.
3. Dixon's plantation, Cooper River.
4. Goose Creek, 15 miles from Charleston.
5. Drayton Hall.

Analysis 1 by Crowell and Peck; analyses 2-5 by C. U. Shepard.

The analyses given above, while showing well the amount of free sand carried by many of these soft Tertiary limestones, hardly represent their percentages of lime carbonate. Much purer beds than these are known to occur near Charleston, but no good analyses are available.

PORTLAND-CEMENT RESOURCES OF SOUTH DAKOTA.

PORTLAND-CEMENT MATERIALS.

The limestone formations of South Dakota which give any promise of supporting a Portland-cement industry occur in two different portions of the State. They are thus separated geographically as well as geologically into the two following groups, which will be discussed in the order named: (1) The limestones of the Black Hills district; (2) the Niobrara (Cretaceous) chalk of eastern South Dakota.

LIMESTONES OF THE BLACK HILLS DISTRICT.

Darton has described the stratigraphy and rocks of the Black Hills district[a] as follows:

The Black Hills uplift is an irregular dome-shaped anticline, embracing in its more obvious features an oval area 125 miles in length and 60 miles in breadth, with its larger dimension lying nearly northwest and southeast. It is situated in a wide area of almost horizontal beds underlying the great east-sloping plain that extends from the Rocky Mountains to the Mississippi River. It has brought above the general surface level an area of pre-Cambrian crystalline rocks about which there is upturned a nearly complete sequence of the Paleozoic and Mesozoic rocks from Cambrian to

[a] Darton, N. H., Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 4, pp. 502 et seq.

Laramie, all dipping away from the central nucleus. There are also extensive overlaps of the Tertiary deposits, which underlie much of the adjoining plains area. The region is one of exceptionally fine exposures, which afford rare opportunity for a study of stratigraphic relations and variations. Many of the rocks are hard, and the streams flowing out of the central mountain area have cut canyons and gorges, in the walls of which the formations are often extensively exhibited. The structure presented locally is that of a monocline dipping toward the plains. The oldest sedimentary rocks constitute the escarpment facing the crystalline rock area, and each higher stratum passes beneath a newer one in regular succession outward toward the margin of the uplift. The sedimentary formations consist of a series of thick sheets of sandstones, limestones, and shales, all essentially conformable in structure. The overlapping areas of the Tertiary deposits extend across the edges of the older formations. The stratigraphy presents many features of similarity to the succession of rocks in the Rocky Mountains of Colorado and Wyoming, but it possesses numerous distinctive local features.

The following is a list of the formations which are exhibited in the uplift, with a generalized statement as to the thickness, characteristics, and age:

Generalized section in the Black Hills region.

Formation.	Character.	Average thickness.	Age.
		Feet.	
Laramie	Massive sandstone and shale.	2,500	Cretaceous.
Fox Hills	Sandstone and shale	250–500	Do.
Pierre shale	Dark-gray shale	1,200	Do.
Niobrara	Chalk and calcareous shale.	225	Do.
Benton group:			
Carlile formation	Gray shales with thin sandstones, limestones, and concretionary layers.	500–750	Do.
Greenhorn limestone	Impure slabby limestone	50	Do.
Graneros shale	Dark shale with lenses of massive sandstone in its lower part at some places.	900	Do.
Dakota sandstone	Massive buff sandstone	35–150	Do.
Fuson	Very fine-grained sandstone and massive shales. White to purple color.	30–100	Do.
Minnewaste limestone	Gray limestone	0–30	Do.
Lakota	Massive buff sandstone, with some intercalated shale.	200–350	Do.
Beulah shale	Pale grayish-green shale	0–150	Jurassic.
Unkpapa sandstone	Massive sandstone; white, purple, red, buff.	0–250	Do.

Generalized section in the Black Hills region—Continued.

Formation.	Character.	Average thickness.	Age.
		Feet.	
Sundance	Dark-drab shales and buff sandstones; massive red sandstone at base.	60–400	Jurassic.
Spearfish	Red sandy shales with gypsum bed.	350–500	Triassic.
Minnekahta limestone.	Thin-bedded gray limestone.	30–50	Permian.
Opeche	Red slabby sandstone and sandy shale.	90–130	Permian?
Minnelusa	Sandstones, mainly buff and red; in greater part calcareous. Some thin limestone included.	400–450	Carboniferous.
Pahasapa limestone	Massive, gray limestone.	250–500	Do.
Englewood limestone	Pink slabby limestone	25	Do.
Deadwood	Red-brown quartzite and sandstone, locally conglomeratic, partly massive.	4–150	Cambrian.

Of the various formations named in the above tables, the limestones are described by the same writer.[a]

ENGLEWOOD LIMESTONE.

In the southern Black Hills the Deadwood formation is overlain by a series of thin-bedded, pale pinkish-buff limestones. On the suggestion of Mr. Jaggar, it is proposed to designate this formation the Englewood limestone, from a locality in the northern Black Hills where it is extensively exposed. It appears to extend continuously around the Black Hills, everywhere immediately underlying the Pahasapa limestone. It averages 20 to 30 feet in thickness and presents frequent outcrops in the lower slopes of the limestone escarpment and in numerous canyons. It merges rapidly into the overlying limestone, occasionally with a few feet of impure buff limestone intervening. It is usually sharply separated from the Deadwood formation, but only by a sudden change in the nature of the materials. The Englewood limestone is usually fossiliferous, containing numerous corals and occasional shells. The following forms have been reported: *Fenestella*, *Orthothetes*, *Leptæna*, *Spirifer*, *Chonetes logani*, *Reticularia peculiaris*, *Syringothyris carteri*, and crinoids. It is correlated with the Chouteau or Kinderhook of the Mississippi Valley.

PAHASAPA LIMESTONE.

This prominent member, heretofore known as the gray limestone, has an extensive outcrop area in the Black Hills uplift. It constitutes much of the high, wide plateau

[a] Ibid., pp. 509, et seq.

west of the central region of crystalline rocks, and is most characteristically exhibited in the great lines of cliffs in the infacing escarpment surrounding that region. Mr. Jaggar has suggested that there be applied to it the Dakota Indian name for the Black Hills—Pahasapa. The formation consists of a thick deposit of massive gray limestone, usually outcropping in precipitous cliffs with many picturesque irregularities of form, or with wide, flat surfaces. Caverns are of frequent occurrence, some of them being of large size. One, having several miles of galleries, is known as Wind Cave, from the strong current of air which usually issues from its mouth. It is situated 8 miles north of the Hot Springs and attracts thousands of visitors. Crystal Cave, in the northern Black Hills, is also a very interesting cavern, with many large deposits of dog-tooth spar on its walls.

The most extensive exposures of the Pahasapa limestone are in the great plateau west of Custer. Here the formation begins in a line of high cliffs surmounting slopes of crystalline schists and the relatively thin sheets of Englewood limestone and Deadwood sandstone. A view of one of these cliffs is shown in fig. 274. In Pennington County the plateau has a width of 10 miles of continuous limestone outcrop, constituting the most elevated area in the Black Hills excepting the small summit of Harney Peak. To the west the limestone passes beneath the sandstone of the Minnelusa formation, but it is exposed again in the arch of the steep anticline near the Wyoming-South Dakota line. Hell Canyon cuts deeply into the Pahasapa limestone, as does also the wider canyon known as Pleasant Valley. East of the crystalline rock area the limestone stands out on many conspicuous knobs, or lies on the eastern slopes of ridges due to the Deadwood quartzite, but it does not attain the high altitude which it has farther west. With decreased thickness, the more rapid dip to the east soon carries the formation below the surface in that direction, but it constitutes the walls of many of the canyons of the streams from Beaver Creek northward. French Creek has extensive cliffs of the limestone, and Spring Creek has cut a long, deep canyon through it.

The thickness of the Pahasapa limestone in the central and southern Black Hills varies from about 500 feet at the northwest to 225 feet on the east and southeast. All along the eastern side of the hills it appears to have the latter thickness, with slight local variations. It does not present any noteworthy lithologic subdivisions, but its upper part is often siliceous and flinty and stained red to a greater or less extent from the overlying red beds of the Minnelusa formation. At its top there is usually a red shaly bed of slight thickness, containing oval concretions of hard silica from 6 inches to 2 feet in diameter in greater part. Fossils occur sparingly throughout the formation, including *Spirifer rockymontanus*, *Seminula dawsoni* (*Athyris subtilita*), *Productus*, and *Zaphrentis*, a fauna which indicates lower Carboniferous age.

MINNEKAHTA LIMESTONE.

This formation, known in previous geological reports as the purple limestone, is a prominent member of the Black Hills series. It is thin, averaging less than 50 feet in thickness, but it is hard and flexible and covers moderately extensive areas of the outer slopes of the Minnelusa formation. Southwest of Hot Springs it constitutes a prominent anticlinal ridge, which extends south to Cascade Spring. It is proposed to designate this formation the Minnekahta limestone, because a distinctive geographic name is required, and the region near the hot springs, originally known as the "Minnekahta" by the Indians, is a typical locality. The springs rise through crevices in the formation just west of the town of Hot Springs, and the exposures in the vicinity show all the characteristic features which the formation presents. The prominence of the Minnekahta limestone outcrops is due largely to the fact that the overlying formation is soft, red shale, which has been deeply eroded, leaving the underlying limestone bare on slopes up which the red shale originally extended.

The underlying formation, the Opeche, also being soft, the limestone nearly everywhere presents an escarpment, and the many canyons which are cut through it have vertical walls of the limestone.

The Minnekahta limestone presents more details of structure than any other formation of the Black Hills. Normally it dips outward away from the central area at from 5° to 30°, but there are frequent variations in the amount and direction. These variations are due to the fact that the formation is a relatively hard bed of homogeneous rock lying between masses of soft, red shales, so that it was free to flex wherever pressure was exerted, the plasticity of the inclosing beds favoring local flexing and warping. Its beds are sometimes traversed by small faults and minute crumplings, but considering the large amount of deformation to which the formation has been subjected the flexures are but little broken. The formation is uniform in character throughout, being a thin-bedded, light-colored limestone containing magnesia and more or less clay as an impurity. Its thin bedding is a characteristic feature, although the thin layers are so cemented together that the formation presents a massive appearance. On weathering and through the action of frost it breaks into slabs usually 2 to 3 inches in thickness. On the western side of the Black Hills, notably in the region from east of Clifton northward, its coloring is slightly darker, varying from dove color to lead gray, and some of the beds present a seminodular structure. An increased admixture of clay is also observed in some layers. The general appearance of the formation is always slightly pinkish, with a tinge of purple, from which the term "purple limestone" originated. The thickness of the formation was measured at many points; a few representative measurements are as follows:

Thickness of Minnekahta limestone.

	Feet.
Spring Creek	45
Battle Creek	40
Hot Springs	50
Stockade Beaver Creek	28-33
Cambria well	34

This relatively uniform thickness indicates very uniform conditions of deposition during the accumulation of the red bed deposits, the Opeche formation below, and the Spearfish formation above. An analysis of a typical sample of the Minnekahta limestone is as follows:

Analysis of Minnekahta limestone.

Constituent.	Per cent.
Lime	31.51
Magnesia	19.85
Alumina, iron, etc	.36
Water	1.25
Carbonic acid	44.66
Sulphuric acid (SO_3)	.07
Silica	1.12
Manganese, soda, and potash	None.

NIOBRARA CHALK.

In the eastern part of South Dakota, and more particularly in the extreme southeastern part of the State, the Niobrara chalk furnishes an excellent raw material for Portland cement manufacture. The composition and stratigraphy of these rocks have been discussed in detail under Iowa (p. 147), and need not be taken up again here. Todd states that the chalk is well exposed in numerous bluffs along the Missouri River from Yankton to Chamberlain, while it also outcrops in smaller isolated elsewhere in the district.

PORTLAND CEMENT INDUSTRY IN SOUTH DAKOTA.

The Western Portland Cement Company, whose plant is located a few miles from Yankton, has employed the Niobrara chalk and the overlying Pierre clay as raw materials. The original plant was a wet process mill, with stationary kilns of the Johnson type, but these have been replaced by rotary kilns. Analyses of the raw materials follow:

Analysis of Portland cement materials, Yankton, S. Dak.

	Chalk.		Clay.	
	1	2	3	4
Silica (SiO_2)	3.83	4.14	61.53	57.98
Alumina (Al_2O_3)	2.31	1.81	20.74	18.26
Iron oxide (Fe_2O_3)		2.72	4.01	4.57
Lime (CaO)	52.16	51.00	5.28	1.57
Magnesia (MgO)	.14	Tr.	1.72	1.83
Sulphur trioxide (SO_3)	.20	.50	1.26	1.28
Carbon dioxide (CO_2)	41.64	37.99	3.09	n. d.
Water		n. d.	n. d.	12.08

1. C. B. McVay, analyist.
2, 3. Mineral industry, vol. 1, p. 52.
4. Mineral industry, vol. 6, p. 97

PORTLAND CEMENT RESOURCES OF TENNESSEE.

By E. O. Ulrich.

Limestones and shales that probably have the chemical composition and other properties required in the manufacture of Portland cement occur abundantly in eastern and middle Tennessee. In eastern Tennessee the more promising materials and localities are confined to the great Appalachian Valley, in which numerous large and easily quarried outcrops of nonmagnesian upper Ordovician limestones and shales alternate with generally much wider bands of dolomitic lower Ordovician limestone and Cambrian shales, sandstones, and limestones.

Very few analyses of Tennessee limestone have been published except of the phosphatic limestones of middle Tennessee. This is to be regretted, since the decision as to which limestones have, and which have not, too great a percentage of magnesia to make them available as Portland cement materials is necessarily left to the judgment of the observer. However, with exact correlations and careful comparisons with limestones of known composition it is possible to attain results sufficiently reliable for the present purpose.

The bands of limestone in the valley in which the magnesian constituent is low enough to permit them to be classed as possible factors in the manufacture of Portland cement lie mostly above the Knox dolomite. They are divisible into two series, one occurring in the eastern half, the other in the western half, of the valley. Though probably contemporaneous, the deposits comprised in each of these two series are sufficiently different in lithologic characters and fossil contents to induce the belief that they were laid down in distinct basins or troughs. The beds composing the two series should therefore be considered separately and under distinct names.

CAMBRIAN AND LOWER ORDOVICIAN LIMESTONES OF EAST TENNESSEE.

Limestones form but a small part of the lower Cambrian rocks in this State. Furthermore, it does not seem probable that any of these beds will have the chemical composition now deemed necessary in a Portland cement material. Certain layers of the Maryville limestone, described and mapped in folios Nos. 12, 16, 25, 27, 33, and 59, published by the U. S. Geological Survey, probably are more promising for the purpose than any other Cambrian limestone in the State. Other limestone beds, ranging in thickness from a few feet to nearly 400 feet, have been described under the names of Beaver and Rutledge limestones. Others again are included as calcareous members in the Nolichucky and Conasauga shale formations.

The great bed of limestone known as the Knox dolomite overlies these lower Cambrian formations. According to classifications now in vogue, the lower half of the Knox is referred to the Cambrian system while the upper half is placed in the Ordovician. So far as known, the percentage of magnesia in no part of the 3,500–4,000 feet of limestone comprised in the formation is low enough to permit the rock to be classed as a possible source of Portland cement material.

UPPER ORDOVICIAN LIMESTONES OF THE EASTERN PART OF THE GREAT VALLEY OF EAST TENNESSEE.

Lenoir limestone.—At the base of the series of Ordovician limestones, shales, and sandstones that overlies the lower Ordovician Knox

dolomite is a rather persistent bed of more or less argillaceous limestone to which Safford long ago applied the name Lenoir limestone. This bed varies greatly in thickness and reaches in some places a thickness of several hundred feet. It corresponds in position, and in a considerable degree also in its lithologic features, to the so-called "Trenton" limestone that is employed in the manufacture of cements in more northern parts of the Appalachian Valley.

The Lenoir outcrops in bands trending approximately parallel with the margins of the valley. In most of these it is overlain by a thick bed of shale that has been mapped in folios issued by the national Survey as the Sevier shale. In the bands found near the eastern edge of the valley, in which the limestone is thin and locally wanting, the lower part of the overlying beds is a dark shale, to which the name Athens shale has been applied. In these bands the shale is overlain by the Tellico sandstone. Where the Athens shale is absent, as in the bands outcropping between Knoxville and Bays Mountain, lying about 8 miles east of that city, the Lenoir limestone is much heavier and extends upward to the base of the Tellico sandstone.

In the folios and other publications of the United States Geological Survey relating to East Tennessee the Lenoir limestone is erroneously regarded as a thin representative, or rather as an extension, of the basal part of the Chickamauga limestone of the western side of the valley. Nearly all the areas of Lenoir limestone in East Tennessee have been mapped as Chickamauga limestone in the folios describing the geology of the Chattanooga, Cleveland, Kingston, Loudon, Knoxville, Maynardville, Briceville, and Morristown quadrangles. In these folios the Lenoir Chickamauga limestone bands may be distinguished from the true Chickamauga areas by the association of one, two, or all of three formations—viz, the Athens shale, Tellico sandstone, and Sevier shale—with the limestone in the former areas and their absence in the latter. The distribution of the Silurian (iron-bearing) Rockwood formation may also be used in discriminating these areas, the easternmost bands of the Rockwood corresponding approximately to the western border of the area to which the Lenoir limestone, Athens shale, Sevier shale, and other formations pertaining to the eastern province are confined.

Locally, especially in the bands that correspond, with respect to the width of the valley, to those occurring in the vicinity of Knoxville, the upper part of the Lenoir contains or consists of heavy beds of red and gray marbles. As shown by the accompanying analyses, these marbles are very pure limestones, being especially low in magnesia. As the outcrops are often close to beds of shale, some of those that for one reason or another have proved unfit to work for marble might still, if found suitable, be utilized in the manufacture of cement.

Analyses of Tennessee marbles from the upper part of the Lenoir limestone.

	1	2
Silica (SiO_2)	0.17	0.13
Alumina (Al_2O_3)	.04	Tr.
Iron oxide (Fe_2O_3)	.23	.26
Lime (CaO)	55.47	55.32
Magnesia (MgO)	.30	.21
Sulphur (S)	....	.005
Carbon dioxide (CO_2)	43.63	43.51
Water	.21	.125

1. Knoxville, Knox County, L. G. Eakins, analyst. Bull. U. S. Geol. Survey No. 168, p. 258.
2. Hawkins County, A. L. Colby, analyst. Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 5, p. 983.

Ordovician limestones above the Lenoir.—Similar and occasionally extensive beds of crystalline and other limestones occur locally in the Sevier shale. Such limestone beds are especially well developed in the bands striking southwest from Knoxville to Athens. Thinner and more earthy beds of limestone occur, though less commonly, also in the Athens shale. In the region between Holston and Clinch rivers the Lenoir limestone is generally overlain by the Moccasin limestone, a reddish argillaceous limestone several hundred feet thick.

UPPER ORDOVICIAN LIMESTONES OF THE WESTERN PART OF THE GREAT VALLEY OF EAST TENNESSEE.

The upper Ordovician limestones of the western half of the valley are all included in a single comprehensive formation, described in publications of this Survey as the Chickamauga limestone. This great mass of rocks, aggregating from 1,200 to 2,000 feet in thickness, consists almost entirely of limestone. Locally and in certain parts of the section, especially toward the top, the limestone becomes shaly, or it may include many thin beds of shale. Though the greater part of the formation may be classed as a pure limestone, it is nevertheless true that many layers contain considerable clayey matter, while a few are siliceous and on decomposition give rise to chert. The percentage of magnesia, however, is almost certainly always low, although analyses establishing the fact are wanting. Highly argillaceous limestones, usually mottled with red, occur in the lower half of the formation, especially in the Chattanooga belt. Many localities in the western half of the valley doubtless would afford materials for a proper mixture in the same quarry.

The Chickamauga limestone contains representatives of practically each and all of the formations into which the Ordovician rocks of

middle Tennessee have been divided. The succession of the various beds, and of the faunas characterizing each, is exactly the same in the two areas, so that there can be little or no doubt respecting the continuity of the beds beneath the later rocks making the intervening Cumberland Plateau.

ORDOVICIAN LIMESTONES OF MIDDLE TENNESSEE.

Limestones of the Stones River group.—The nearly horizontal limestones of this group form the floor of the basin, the lowest formation outcropping at Murfreesboro. They are all essentially nonmagnesian, and hence deserve mention as possible or promising materials. The Murfreesboro limestone, with an exposed thickness of 70 feet, is light blue, usually heavy bedded, occasionally rather earthy, and often very cherty. Murfreesboro is situated near the center of the area in which this limestone comes to the surface. The diameter of the area, which includes, also, small outliers of later formations, ranges from 12 to 14 miles.

The Pierce limestone, having a maximum thickness of scarcely 30 feet, rests on the Murfreesboro limestone and forms a narrow belt around the outcrops of that formation. It consists chiefly of thin layers of highly fossiliferous pure or somewhat argillaceous limestone interbedded with thin seams of calcareous shale.

The next formation, the Ridley limestone, having a thickness of from 80 to 100 feet, consists of thick-bedded, light-blue, sparsely cherty limestone. The Ridley, like the Pierce, outcrops in an irregular circular band around the Murfreesboro area. Limited exposures of its upper beds occur also in Bedford and Marshall counties.

The Lebanon limestone has lithologic characters similar to those of the Pierce limestone. It is the fourth formation from the base of the Stones River group, has a thickness of 100 feet or more, and occupies a larger area than the preceding limestones. The towns of Lebanon, Lewisburg, Shelbyville, La Vergne, and Fosterville are located on this limestone. It is shown also in the bluffs of Duck River at Columbia. A considerable proportion of the bed consists of argillaceous limestone.

The Carter limestone, the uppermost division of the Stones River group, is a very light blue, compact, heavy-bedded limestone, 40 to 80 feet thick. It occurs in all of the counties in the central basin, and is more often burned for lime than any other of the Ordovician limestones of the basin.

Trenton group.—The Trenton limestones, including the Hermitage, Bigby, and Catheys limestones, as defined in the Columbia folio,[a] form a wide but irregular belt, completely encircling the central Stones River limestone areas of the basin.

These Trenton formations, though consisting almost entirely of limestone, still vary greatly from place to place in their lithologic characters. The Bigby limestone, for instance, is granular and phosphatic on the west side of the basin. Both of these peculiarities are lost on tracing the formation around the northern and southern sides to the eastern border. Here a large part of the formation, which has, moreover, increased in thickness, consists of compact earthy limestones.

The Trenton limestones in the counties bordering the Cumberland River, if the present local scarcity of fuel is not prohibitive, are particularly promising materials. Coal was formerly boated down from eastern Kentucky mines, and these shipments might be resumed if there was sufficient reason. At present only points in the vicinity of Nashville and Carthage have access to coal brought in by railroads. At both of these places, however, there is such a variety of limestone and shales that it is scarcely to be doubted that abundant materials affording the proper mixture are available at either.

Leipers formation.—This formation consists, as a rule, of interbedded shales and apparently nonmagnesian, thin, knotty limestones. It varies considerably in composition from place to place, and even in the same outcrop, and on this account is not deemed so promising as most of the underlying Trenton and Stones River formations. The Leipers outcrops chiefly in the slopes of the highland rim. Stratigraphically it is equivalent to the formation in the hills about Cincinnati, Ohio.

SILURIAN LIMESTONES.

The Silurian rocks of Tennessee embrace three limestone formations containing beds sufficiently low in magnesia to be considered available as Portland cement materials, viz, the Clifton limestone (Niagara), the Linden limestone (Helderberg) of middle and western Tennessee, and the Sneedville or Hancock limestone (Helderberg) of northeastern Tennessee. The Clifton and Linden limestones outcrop chiefly along the Tennessee River, and both, the Linden especially, contain interstratified beds of shale. Locally, the Clifton contains beds that are more or less highly argillaceous. These argillaceous limestones occur principally in the lower part of the formation. Locally, as in the bluffs opposite Centerville, in Hickman County, they may afford material suitable for so-called natural Portland cements.

MISSISSIPPIAN LIMESTONES.

Nonmagnesian limestones occur in three Mississippian formations in Tennessee. The lowest of these is the Tullahoma formation, in which the limestones are prevailingly very siliceous and cherty, and for this

[a] Geologic Atlas U. S., folio 95, U. S. Geol. Survey, 1903, pp. 1-2.

reason probably not of importance in this connection. The principal outcrops of the Tullahoma form the barrens of the highland rim and occur in the counties immediately surrounding the central basin.

The next division is the St. Louis limestone. This formation covers the higher points of the highland rim and forms the surface rock over a wide belt of country along the western base of the Cumberland table-land. Livingston, Sparta, Cookeville, and McMinnville are among the towns located on this belt. Another large outcrop covers the greater parts of Robertson, Montgomery, and Stewart counties, which adjoin counties in southwestern Kentucky in which the same formation prevails. The St. Louis limestone is from 200 to 300 feet thick and consists mainly of gray and blue, thick-bedded, cherty limestone. Near its base, however, especially in Montgomery County, the formation often includes many beds of high-grade limestone. Where such beds occur they are sometimes underlain by oolitic and semioolitic limestone regarded as of the same age as the Spergen limestone of Indiana.

In Tennessee the Chester group consists largely of limestone, which, as it rests directly upon the St. Louis limestone, has been described together with that formation by Hayes and others as a single formation under the name Bangor limestone. In his reports Stafford usually refers to the Chester as the "Mountain limestone."

The Chester is limited to the eastern half of the State. It forms the base or part of the slopes of the Cumberland table-land on all its sides. Interbedded with the limestone are numerous beds of often highly-colored shales and several comparatively unimportant sandstones. The shales grow relatively more abundant toward the top of the formation.

PORTLAND-CEMENT RESOURCES OF TEXAS.

By J. A. Taff.

PORTLAND-CEMENT MATERIALS.

A number of limestone formations occur in the Carboniferous and older Paleozoic rocks in north-central Texas and in ~~the Trans-~~Pecos region, and a limestone has also been located near the base of the Tertiary in Limestone County. These limestones may prove to have compositions adapted to the production of certain classes of cement, but the constituents have not been determined.

Of the many limestone formations in the geological column of Texas those of widest extent and greatest purity and therefore those best adapted for use in making Portland cement are of Cretaceous age.

The Cretaceous of Texas occurs in a wide belt of country, extending across the central part of the State in a north-south direction from Red River to the Rio Grande. It makes the most fertile lands in the

most densely populated portion of the State. The cities of Sherman, Dallas, Fort Worth, Waco, Austin, and San Antonio are located upon it. Facilities of transportation are ample, for railroads extend from the principal cities to other centers of population in the State and beyond.

Two formations in the Cretaceous system contain limestone deposits of remarkable purity that are well adapted to the manufacture of Portland cement. These formations are the Austin chalk and Goodland or Comanche limestone.

AUSTIN CHALK.

The Austin chalk is situated in the lower part of the Gulf series (Upper Cretaceous). Its exposed area is shown in the sketch map (Pl. XIV). From a point on Red River near the northeast corner of the State its outcrop bears westward, passing near Clarksville, Honeygrove, and Paris, to Sherman. From Sherman its course bears southwestward beneath Dallas, Waco, Austin, and San Antonio. Besides these, numerous other but smaller cities are situated upon it, from San Antonio its course westward paralleling the Southern Pacific Railway to the Rio Grande near Del Rio.

The rock is a massive white friable limestone or chalk. Through several hundred feet from near the base to the top the rock varies from 70 per cent to 90 per cent carbonate of lime, as shown in the table of analysis of Texas chalk. Massive beds of many feet in thickness are remarkably uniform in texture and composition.

Analyses of Texas chalk and marl.

No.	Silica, SiO_2, and insoluble.	Ferric oxide and alumina, Fe_2O_3 and Al_2O_3.	Lime, CaO.	Magnesia MgO.	Carbonate of lime, $CaCO_3$.	Carbonate of magnesia $MgCO_3$.
1	5.77	2.14	50.45	0.28	90.15	0.58
2	5.94	1.72	48.73	....	86.57	....
3	10.32	6.56	45.30	....	79.75	....
4	11.31	7.50	42.61	....	76.47	....
5	15.98	8.47	38.86	....	70.60	....
6	48.02	20.95	14.26	....	24.62	....
7	60.82	21.30	3.66	....	6.51	....
8	23.55	1.50	39.32	.28	70.21	.58

1. Fresh rock from quarry, average material used in the manufacture of cement, Alamo Cement Works, 3 miles north of San Antonio, Tex.
2. Brushy Creek, Williams County, Tex., 100 feet above base of chalk.
3. Brushy Creek, Williams County, Tex., middle part of chalk.
4. Brushy Creek, Williams County, Tex., upper part of chalk.
5. San Gabriel River, Williams County, Tex., chalk marl at top of white chalk.
6. Williams County, Tex., lower part of blue marl above the white chalk.
7. Williams County, Tex., greensand marl, central part above blue marl.
8. Average fresh rock from quarry, Texas Portland Cement Works, 3 miles west of Dallas, Tex., lower 20 feet of white chalk.

Near Red River, east of Sherman, the chalk probably does not exceed 400 feet in thickness and it is interbedded with chalk marls. Here, however, there are thick beds of nearly pure chalk. Between Sher-

SHOWING DISTRIBUTION OF LIMESTONE SUITABLE FOR PORTLAND CEMENT

Scale

25 0 25 50 75 100 miles

1904

Cretaceous chalk

Carboniferous limestone

Cambrian Ordovician, and Silurian limestones

man and Austin the formation is approximately 600 feet thick, and is generally uniform in texture and composition. From Austin southwestward the chalk probably increases in thickness, but it is broken and in part concealed by faulting.

The chalk has clay marls in contact both above and below. It grades upward into chalk marl, which in turn is followed by limy clay, bringing into close relations all of the elements essential to the production of Portland cement.

The Austin chalk is structurally well situated for quarrying. East of Sherman it is inclined southward and south of Sherman southeastward at approximately 40 feet per mile.

GOODLAND LIMESTONE.

The Goodland limestone is near the middle of the Comanche (Lower Cretaceous) series in Texas and southern Indian Territory. It is situated west of and generally parallel with the outcrop of the Austin chalk. It crops out in southern Indian Territory east of Ardmore. Near Ardmore the outcrop turns southward, crossing into Texas in Cooke County. It occurs in large areas in Wise, Parker, Hood, Erath, Bosque, Hamilton, Coryell, Lampasas, Burnet, Blanco, Kendall, Comal, and Bexar counties. Still larger areas are exposed in the Edwards Plateau west of San Antonio.

In Indian Territory and in Texas north of the Brazos River Valley the formation is a massive, semicrystalline white limestone 30 to 50 feet thick. From Brazos River Valley southward it gradually increases in thickness, reaching 300 feet on Colorado River. In this central Texas region the formation divides into two parts. The lower part consists of a massive white chalky limestone nearly 100 feet thick. This member has been described in Texas and United States Geological Survey reports as the Comanche Peak limestone. The upper member, which has been described as the Edwards limestone, consists of thick beds of nearly pure chalky and siliceous limestone beds alternately stratified. They contain quantities of nodular and almost pure flints. The flints occur in both classes of rock, but are rather more abundant in the pure limestones. Near Austin and elsewhere in the central part of the State these purer limestones are manufactured into a high grade of white lime.

The Goodland limestone and its southern equivalents are found capping escarpments overlooking the timbered lands of the Trinity sands in northern Texas and Indian Territory. In central Texas these limestones occur in a region of strongly incised drainage channels, and cap local table lands in the western part of their area of outcrop and occur in escarpments, bluffs, and low lands in the eastern part.

Like the Austin chalk, the Goodland limestone lies almost flat, being inclined at low angles toward the south in Indian Territory and toward the east and southeast in Texas.

PORTLAND-CEMENT INDUSTRY IN TEXAS.

Three cement mills have been started in Texas, located at Austin, Dallas, and San Antonio, respectively. All of these mills have set limestone from the Cretaceous beds. The Austin plant has been shut down for some time; the Dallas plant has recently been purchased by the Iola Portland Cement Company of Kansas.

PORTLAND-CEMENT RESOURCES OF UTAH.

Limestones, usually low in magnesium carbonate, occur at many points in the Wahsatch Mountain area in Utah. Most of these limestones are of Carboniferous age. Frequently they contain so much clayey matter as to fall below 75 per cent in lime carbonate, in which case they are to be regarded as approaching the Lehigh cement rock (see Pennsylvania) in composition. A rock of this type would require the addition of a purer limestone in order to bring it up to the proper percentage of lime for a Portland-cement mixture.

In the Plateau district softer limestones, of Eocene and later age, occur.

Analyses of limestones from Utah.

	1	2	3	4	5	6	7	8	9
Silica (SiO_2)	0.57	17.19	4.33	2.37	27.94	13.61	5.89	4.03	19.24
Alumina (Al_2O_3)	n. d.	n. d.	n. d.	.25	.35	3.72	1.09	.20	3.26
Iron oxide (Fe_2O_3)	.90	.48	.63						1.09
Lime (CaO)	55.22	43.78	52.34	53.09	39.54	43.23	42.49	51.33	38.94
Magnesia (MgO)	.41	.91	.60	1.20	.29	2.18	8.50	.72	2.75
Alkalies (K_2O, Na_2O)	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	.63	Tr.
Sulphur trioxide (SO_3)	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	......	.89	.53
Carbon dioxide (CO_2)	43.84	35.40	41.78	42.88	31.69	36.20	n. d.	41.07	29.57
Water	n. d.	n. d.	n. d.	.22	.25	1.17	n. d.	.83	1.67
Organic matter	......	......	......	......	......	......	......	.27	2.96

1. Carboniferous limestone, Mammoth Peak, Tintic district, Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 2, p. 625.
2. Carboniferous limestone, Sioux Peak, Tintic district, Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 2, p. 626.
3. Carboniferous limestone, Eureka Peak, Tintic district, Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 2, p. 623.
4. Carboniferous limestone head of Mill Canyon: B. E. Brewster, analyst. Rept. Fortieth Parallel Survey, vol. 2, p. 376.
5. Carboniferous limestone, Ute Peak: B. E. Brewster, analyst. Rept. Fortieth Parallel Survey, vol. 2, p. 288.
6. Silurian (?) limestone, base of Ute Peak: B. E. Brewster, analyst. Rept. Fortieth Parallel Survey, vol. 2, p. 411.
7. Eocene limestone, Manti: Geo. Steiger, analyst.
8. Oolitic sand, shores of Salt Lake: T. M. Chatard, analyst. Bull. U. S. Geol. Survey No. 27, p. 69.
9. Calcareous adobe soil, Salt Lake City: L. G. Eakins, analyst. Bull. U. S. Geol. Survey, No. 64, p. 51.

One cement plant is at present in operation in Utah. This is the mill of the Portland Cement Company of Utah, located in Salt Lake City. The quarry from which the raw materials are obtained is in Parleys Canyon, several miles southeast of the city. Two types of

limestone are obtained here, one a cement rock, high in clayey matter, the other a relatively pure limestone. These are mixed in proper proportion for Portland cement.

Analyses of Portland cement materials used in Salt Lake City, Utah.

	High-lime rock.		Low-lime rock.	
Silica (SiO_2)	4.70	6.8	18.90	21.2
Alumina (Al_2O_3)	1.73	3.0	7.05	8.0
Iron Oxide (Fe_2O_3)	1.42		2.85	
Lime (CaO)	50.96	50.3	36.74	35.2
Magnesia (MgO)	.58	.36	2.70	1.8

PORTLAND CEMENT RESOURCES OF VERMONT.

Vermont, unlike the other New England States, contains extensive and important deposits of nonmagnesian limestones and marbles. These deposits are worked at present for building stone and lime burning.

The limestones quarried in Vermont fall into two distinct groups. The first group contains the crystalline limestones (marbles), worked extensively in the vicinity of Rutland, West Rutland, Dorset, and Brandon. The material obtained in this area is well known commercially as the "Vermont marble." The second group of limestones includes those quarried in northwestern Vermont, the principal workings being near Swanton, Highgate Springs, Winooski, and Leicester Junction. These limestones are mostly of Ordovician age (Chazy and Trenton), are not markedly crystalline, and commonly range in color from dark gray or blue to almost black.

Both types—the marbles and the black limestones—are usually very low in magnesia, as may be seen from the analyses below.

Analyses of Vermont limestones.

	1	2	3	4	5	6	7	8	9
Silica (SiO_2)	0.35	0.63	0.63	0.40	0.28	0.40	0.70	0.22	0.62
Alumina (Al_2O_3)	.20	.....	.05	.10	.30	.20	.15		
Iron oxide (Fe_2O_3)		.05	.34						
Lime (CaO)	55.00	53.93	55.09	55.83	55.27	55.26	55.50	55.15	54.95
Magnesia (MgO)	.25	1.47	.37	Tr.	.28	.15	Tr.	.57	.59
Carbon dioxide (CO_2)	44.02	43.96	43.68	43.65	43.82	43.66	43.65	44.00	43.80

1, 2. Proctor, Rutland County. Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 3, p. 809.
3. Columbian Marble Company, Proctor. Penfield, analyst. Twentieth Ann. Rept. U. S. Geol. Survey, pt. 6, p. 447.
4. Felton Quarry, Highgate Springs. S. P. Sharples, analyst. Twentieth Ann. Rept. U. S. Geol. Survey, pt. 6, p. 456.
5, 6, 7. Vermont Marble Company, West Rutland. Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 3, p. 808.
8, 9. Vermont Marble Company, West Rutland. J. N. Harris, analyst. Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 3, p. 808.

So far as composition is concerned, both the marbles and the ordinary limestones are well suited for use as Portland cement materials. Fuel, however, is expensive; there are no good local markets for cement and cement products, and satisfactory clays are rather difficult to obtain. Commercial conditions, therefore, seem to rule these otherwise excellent Vermont limestones out of consideration. If conditions were different, a flourishing Portland-cement industry might be established, as a cement plant could utilize the enormous amount of waste material from the marble quarries.

PORTLAND CEMENT RESOURCES OF VIRGINIA.

By R. S. Bassler.

PORTLAND CEMENT MATERIALS.

Four prominent sources of Portland cement material appear in Virginia. Listed in geologic order, these are:

4. Tertiary soft limestones ("marls").
3. Greenbrier (Lower Carboniferous) limestone.
2. Lewistown (Lower Helderberg) limestone.
1. Ordovician (Trenton, etc.) limestones.

The Tertiary limestones, often called "marls," but entirely different from the fresh-water marls of northern States, occur in eastern or tidewater Virginia. At present their distribution and composition are not sufficiently known to justify discussion. The remaining three groups occur in western Virginia, in the Great Valley and its foothills. Of these three the Lewistown limestone is now used in Portland cement manufacture at Craigsville, while the Greenbrier limestone will probably be an important source of cement material in southwestern Virginia. The general distribution of both these formations is shown in the accompanying map (Pl. XV), but little is known concerning the details of their composition and local distribution. With regard to the fourth and most important group—the Ordovician limestone—the case is different, for a very careful examination has been made of the Trenton and other Ordovician limestones in the valley of Virginia.

For many years the argillaceous Trenton limestones of the Lehigh district of Pennsylvania have furnished the raw material for the manufacture of the greater part of the Portland cement output of the United States. Because of this enormous output the argillaceous limestones of this relatively small district have assumed a great economic importance, and the occurrence of the same rock in other sections of the country is not without considerable interest.

In the early part of the field season of 1904 the writer spent six weeks in the Lehigh and Lebanon valleys of Pennsylvania in a general study of the paleontology and stratigraphy of the Ordovician strata, but particularly in mapping the distribution of the Trenton limestone or cement rock. Later in the season about three weeks were devoted

to similar work in the southern half of the Valley of Virginia. The following preliminary report is based largely upon this later field work, but in its preparation free use has been made of the Staunton folio[a] by N. H. Darton, and of an article by Charles Catlett, entitled "Cement Resources of the Valley of Virginia."[b] Acknowledgments are also due to Prof. H. D. Campbell, of Washington and Lee University, for the use of manuscript geologic maps prepared by him, covering the region about Lexington and Natural Bridge, Va. Mr. Catlett has also kindly allowed the writer to make use of notes and preliminary analyses made by him of the rocks in the vicinity of Harrisonburg and Staunton, Va.

A somewhat more detailed report, with maps, by the present writer, will be found in Bulletin U. S. Geol. Survey No. 260. During the season of 1905 further investigations will be made in the field, in cooperation with the Virginia Geological Survey, and a complete report on the cement resources of Virginia will be published at the close of this field work.

In the present report only that part of the valley lying between Woodstock, in Shenandoah County, on the north, and Natural Bridge, in Rockbridge County, on the south, is considered.

The raw materials occurring in the valley of Virginia that are suitable for the manufacture of cement are argillaceous limestones, pure limestones, shales, and calcareous marls. Of these the more important are the argillaceous and pure limestones.

The principal rock formations in the Valley of Virginia are a great series of limestones termed the Shenandoah limestone and a series of shales named the Martinsburg shales. In general the entire valley is underlain by the Shenandoah limestone, while the shales usually outcrop along the base of the mountains bounding it. Both of these formations yield an abundance of the raw materials required in the manufacture of Portland cement.

SHENANDOAH LIMESTONE.

This is a very great, thick formation, composed of several members. The chemical composition of its several divisions varies greatly. Some of the limestones are highly magnesian; others are almost pure calcium carbonate; while one group contains a considerable amount of clayey material. In the Shenandoah limestone four divisions may be recognized, based on character of the rock and its fossils. These, named in ascending order, are as follows: (1) A series of dolomitic limestones from 1,000 to 2,000 feet thick, of Cambrian age; (2) 300 or more feet of cherty limestone bearing fossils of Beekmantown (Calciferous) age; (3) 60 to 100 feet of a coarsely crystalline light-colored highly fossiliferous limestone, and (4) 200 to 350 feet of dark-colored

[a] Geologic Atlas, U. S., folio 14, U. S. Geol. Survey, 1894.
[b] Bull. U. S. Geol. Survey No. 225, 1904, pp. 457–461.

argillaceous limestone, the Trenton cement rock. Members 1 and 2 are apparently uniformly developed throughout the valley, but 3 and 4, although widely distributed, are sometimes absent.

CAMBRIAN LIMESTONES.

On account of the lack of continuous exposures and the difficulties in distinguishing the various beds the thickness of this division has not been definitely ascertained, but it is certainly not less than 1,000 and may exceed 2,000 feet. Fossils are practically absent in these rocks in this part of the valley, but farther north, notably at several localities in Pennsylvania and New Jersey, a sufficient number of determinative fossils have been found to indicate that probably the entire division is of Upper Cambrian age. These limestones are underlain by a quartzite containing Lower Cambrian fossils, so that although the two formations are apparently conformable there is a great time break between them.

These Cambrian limestones are massive bedded, vary from dark gray to light gray or light blue in color, and are nearly always highly magnesian in composition. Toward the base purple or silvery shales are sometimes seen, but as a rule the entire formation is one of heavily bedded magnesian limestones.

On account of the high percentage of magnesia these limestones are of no value for the manufacture of Portland cement, but their composition does not preclude their use in making natural cement. At the plant at Glasgow, in Rockbridge County, natural cement has been burned for many years from the magnesian limestones of the lower part of this division. Cement from this plant was used in building the locks of the James River and Kanawha Canal.

Occasionally, however, strata of pure nonmagnesian limestone are interbedded with the more typical magnesian rock, and it is these strata that will prove valuable in Portland-cement manufacture. Such strata have been observed in various parts of the valley, but their outcrops are more or less scattered. On account of this fact and of the geologic structure of the entire formation and the small per cent the pure limestones contained in it, these nonmagnesian strata can not be definitely mapped and must be determined in the field. In New Jersey and Pennsylvania there is the same arrangement of a few strata of nonmagnesian limestone with a great series of dolomite, and the former is the source of part of the limestone used in the Lehigh district to bring to the cement rock the required percentage of calcium carbonate. Near Annville, Pa., these nonmagnesian limestones occur in greater quantities than usual, and here much of this limestone is quarried for shipment to cement plants.

BEEKMANTOWN LIMESTONE.

The Cambrian dolomitic limestones grade upward imperceptibly into another series of strata that have essentially the same chemical composi-

U S GEOLOGICAL SURVEY

MAP SHOWING DISTRIBUTION OF LIMESTONES IN VIRGINIA, W

By Edwin C. Ec

Scale

25 0 25 50

1904

LEGEND

Greenbrier limestone

Lewistown limestone and shales

Cambro-Ordovician limestones
Including the Trenton limestone (non-magnesian) and the Kittatinny or Knox limestone (magnesian)

ST VIRGINIA, MARYLAND, AND PART OF PENNSYLVANIA

100 miles

tion, but differ in that extensive layers of chert are interbedded with the usual dolomites. The areas occupied by this division may usually be recognized by their topographic features, for the cherts give rise to conspicuous hills or ridges. Chestnut Ridge, Sugar Loaf, and Betsey Bell are examples of this topography in the vicinity of Staunton, but similar ridges and knolls are encountered throughout the valley. The Beekmantown age of this series has been determined from gasteropod and cephalopod remains found at various points in the valley, particularly in the vicinity of Lexington, Va. On account of this gradual passage of the Cambrian into the Beekmantown, the determination of the thickness of the latter division is difficult. However, the characteristic fossils have been found 300 to 400 feet below the top of the cherty layers, so that their thickness is not less than the figures mentioned. The difficulty of separating these two divisions without evidence furnished by fossils is in accordance with a fact that has often been noted, namely, that wherever both are made up of limestone sedimentation has apparently continued through Upper Cambrian and Beekmantown times without interruption.

Usually no important pure limestone layers have been noticed in this division, and for this reason, as well as for the reason that the topography often accompanying its exposures is unfavorable to quarrying, the rocks of this age are of little value as a source of Portland-cement rock. In a few instances, however, lenses of comparatively pure limestone have been found in this formation as well as in the underlying Cambrian. The following analysis of a sample of this rock from the vicinity of Staunton is typical:

Analysis of pure limestone from vicinity of Staunton, Va.

[Charles Catlett, analyst.]

Silica (SiO_2)	1.79
Alumina (Al_2O_3) Iron oxide (Fe_2O_3)	.74
Lime (CaO)	50.36
Magnesia (MgO)	1.79
Carbon dioxide (CO_2)	41.36
Alkalis, etc	3.97

TRENTON LIMESTONES.

Under this general name two distinct series of limestones are here recognized, the older being a coarsely crystalline highly fossiliferous rock and the younger the well-known black argillaceous limestones or cement rock. The first series is well developed in the area south of Staunton, where it varies from 60 to 100 feet in thickness, while north of Staunton it is apparently missing altogether, for here only the cement rocks occupy the interval between the Beekmantown limestones and Martinsburg shales. At first sight these two would appear to be but phases of one and the same formation, but this idea is dis-

proved by the development of both series in the vicinity of Lexington, Va. Fossils are abundant throughout both series, the first often being crowded with ramose bryozoa and masses of *Solenopora*, while brachiopods, ostracods, and trilobites of Trenton age predominate in the second. Although samples of the coarsely crystalline limestones run high in lime, the strata as a whole contain so much chert that they are of little value for mixture with the cement rock.

Character of cement rock in valley.—The youngest member of the Shenandoah limestone, the argillaceous Trenton, or "cement rock," usually resembles the corresponding strata in the Lehigh district more in chemical composition than in physical aspect. In Pennsylvania the cement rock is usually a dark-gray or black, slaty limestone, which, on account of the shearing to which it has been subjected, breaks under the hammer into flat pieces with smooth, glistening surfaces. As the rock loses its argillaceous character—i. e., as the percentage of lime carbonate in it increases, it loses the slaty appearance and becomes a light-gray crystalline limestone. In the valley, however, the metamorphism seems not to have been so great and the aspect of the limestones varies according to their composition. For example, the rocks of the formation outcropping near Woodstock are little more than compact hardened strata of calcareous mud while, on the other hand, the same horizon on the western side of the valley is occupied by tough, crystalline dark blue or black limestones.

South of Staunton, especially in the vicinity of Lexington, the Trenton strata have been closely folded and compressed and show considerable metamorphism. The result is that the argillaceous limestones in that locality resemble those of the Lehigh district more than at any other point in the valley.

Analyses of these rocks are given under the discussion of the localities in detail.

General distribution of argillaceous Trenton limestone.—On account of the geologic structure of the valley, the argillaceous limestones are found in three well-defined belts. Two of these belts are formed by the outcropping edges of the syncline that forms Massanutten Mountain, while the third follows the western edge of the valley. Exposures of the easternmost belt are found at numerous places along a northeast-southwest line extending from a point about 5 miles east of Woodstock to Fishersville. The next belt to the west parallels this and shows many outcrops along a similar line from Woodstock to Staunton. At several places along these lines of outcrop the argillaceous limestone is missing. The arrangement indicated is most pronounced (1) in the region just south of Massanutten Mountain, having McGaheysville on its eastern edge; and (2) in the area south of Staunton, bounded by Staunton, Barter Brook, and Fishersville. The third belt occurs along the western edge of the valley and parallels the other

two. Here, however, these limestones are often cut out by the great overthrust fault of this portion of the valley.

In this section the best exposures of these rocks are found along the eastern edge of Little North Mountain, especially in the vicinity of Dry River north of Stokesville. The valley proper, as has been remarked before, is usually occupied by the dolomitic limestones, but occasionally synclines exposing the argillaceous limestones and shales are found. The most important of these from an economic standpoint occurs just west of Harrisonburg. In the region near Lexington and Natural Bridge these limestones have been compressed into close folds and cover much wider areas than they occupy in regions lying farther north. Among these wider areas that in which Lexington is located is most favorably situated for cement making; the rest, as a glance at the map will show, being too far away from railroad facilities.

MARTINSBURG SHALE.

The highest formation in the valley proper, geologically speaking, is a great series of gray, light brown or black shales varying in thickness from 1,000 to 1,500 feet. When the Trenton limestones underlie the shales the passage from the one formation to the other is often so gradual that no marked distinction can be observed. Even when the shales rest upon older formations than the Trenton argillaceous limestone, their lower beds are often calcareous and may include thin layers of impure limestone. Although the calcareous portion of the shales may burn to cement when mixed with other materials, it is probable that the main value of this series will be found in its noncalcareous portions, which may be used for mixture with high lime argillaceous rock. The following analyses show the composition of the lower calcareous part and also of the higher, more typical shales:

Analyses of Martinsburg shales in Virginia, New Jersey, and Pennsylvania.

	1	2	3	4	5	6	7
Silica (SiO_2)	68.62	68.00	56.60	76.22	23.08	19.92	19.28
Alumina (Al_2O_3)	12.68	14.40	21.00	13.05	11.08	10.76	9.86
Iron oxide (Fe_2O_3)	4.20	5.40	5.65				
Lime (CaO)	......	2.68	3.42	2.67	35.89	37.05	36.42
Calcium corbonate ($CaCO_3$)	2.34	......	......	......	......	......	......
Magnesia (MgO)	......	1.51	2.30	.93	.94	1.72	1.08
Magnesium carbonate ($MgCO_3$)	3.76	......	......	......	......	......	......
Alkalis	3.73	.11	.50	......	......	......	......
Carbon dioxide (CO_2)	......	2.30	2.20	......	......	......	31.70
Water (H_2O)	4.47	2.70	3.00	......	......	......	......

1. East Bangor, Pa., Twentieth Ann. Rept. U. S. Geol. Survey, pt. 6, p. 436.
2. 1 m. northwest of Colemanville, N. J., Geology New Jersey, 1868, p. 136.
3. Delaware Water Gap, N. J., Geology New Jersey, 1868, p. 136.
4. Lafayette, N. J., Rept. New Jersey State Geol. for 1900, p. 74.
5-7. Calcareous Martinsburg shale, Staunton, Va. (Charles Catlett, analyst.)

CALCAREOUS MARLS.

Small deposits of calcareous tufa have been noticed in various parts of the valley, and these, if favorably located and sufficiently large, would undoubtedly be of much value in cement manufacture. Of more importance, however, are the deposits of calcareous fresh-water marl which have been found scattered throughout this region. In certain portions of Staunton, as has been noted by Mr. Catlett, the foundations of houses are cut in marl 10 to 12 feet deep. The surface indications of these marls are usually so meager that no estimate of their quantity or extent can be determined from these alone.

DETAILS OF LOCALITIES.

An exploration starting at Woodstock, in the northernmost part of the valley visited, and ending in the vicinity of Natural Bridge, disclosed the more favorable localities showing good exposures of the argillaceous limestone, which are briefly discussed below. In indicating advantageous sites for cement plants, the writer means to imply simply that the cement rock and pure lime deposits occur at the places mentioned and that the transportation and other necessary facilities are at hand. Whether a good cement can be made from the raw materials found at these places is a matter which can be determined only by experimentation on a commercial scale. The argillaceous limestones in most instances have a composition very similar to good cement materials of other regions, but this does not necessarily indicate that they also will make a first-class cement.

Woodstock and vicinity.—About 350 feet of argillaceous Trenton limestones are exposed just east of Woodstock, the town itself being situated upon cherty limestones of Beekmantown age. These limestones and the overlying shales dip southeastward at an angle of about 45°, and lie on the outcrops of the western edge of the great syncline forming Massanutten Mountain. Practically the same thickness of cement rock is exposed northeast and southwest of Woodstock. As this line of outcrop is paralleled by the Southern Railroad, which is at no place more than 3 miles distant, numerous sites favorable for cement plants are available. The most prominent location, however, is the immediate vicinity of Woodstock, since here the cement rocks outcrop on the western side of the North Fork of the Shenandoah River. Farther south the river flows between the railroad and the line of cement rock outcrop and would thus greatly increase the cost of a spur line.

Pure limestone for mixture with the cement rock can be found in the immediate vicinity, more probably in greatest quantity just west of the town. Limestone strata, high in calcium carbonate and low in magnesia, were found interbedded with the dolomites west of Wood-

stock, and more extended search will no doubt reveal an ample supply of such stone.

Good railroad facilities, both for obtaining the fuel supply and for shipping the finished material, are found at this place. Coal could be had from the north via the Baltimore and Ohio and Southern railroads, and from the south over the Chesapeake and Ohio, the Valley Branch of the Baltimore and Ohio and the Southern railroads. By the same railroads the finished product could be shipped to the east and to tidewater.

Some miles east of Woodstock this same succession of rock is encountered along the eastern edge of Massanutten Mountain. The cement rocks here occur along a northeast-southwest line paralleling the belt along the western side of the mountain. Along this eastern belt the argillaceous limestones have practically the same composition as those exposed near Woodstock.

The following analysis is typical for this eastern belt:

Analysis of typical limestone near Woodstock.

Calcium carbonate ($CaCO_3$)	74.14
Magnesium carbonate ($MgCO_3$)	1.00
Silica (SiO_2)	16.34
Oxides (R_2O_3)	7.49
Water (H_2O)	2.00

Broadway and Timberville.—Cuts along the Southern Railroad in the vicinity of these two towns show the presence of small synclines of shales and argillaceous limestones very similar in texture and composition to the same rocks found farther south about Harrisonburg.

Harrisonburg and vicinity.—A syncline showing the Trenton argillaceous limestones and Martinsburg shales occurs just west of Harrisonburg, and extends northeast and southwest for a distance of several miles. The cement rock is especially well shown along the street just west of the Southern Railroad depot, but exposures of the shales and of the underlying argillaceous rocks may be seen along the country roads going northwest, west, and southwest from the town. The thickness of the argillaceous limestones in this vicinity could not be determined with certainty because of the lack of continuous exposures, but it probably does not fall short of 200 feet. Fossils indicating the Trenton age of the strata were not uncommon in the rocks shown along the western edge of the town.

Pure limestone deposits are found east and southeast of Harrisonburg in considerable quantity. Exposures of this rock may be seen in a cut on the Chesapeake and Western Railroad just east of the crossing with the Southern Railroad. Here a pure gray limestone is found having a composition shown in analysis No. 1 of the table given below.

From 75 to 100 feet of argillaceous limestones and calcareous slates are exposed in a cut on the Chesapeake and Western Railroad southwest of Harrisonburg and just west of the Southern crossing. Samples from this cut were analyzed by Charles Catlett, with the result shown in No. 2, below.

About 1½ miles north of Harrisonburg the Southern Railroad passes through a cut about 20 feet high and 400 to 600 feet in length, exposing comparatively horizontal slaty limestones. Upon analysis this was found to have the composition shown in No. 4.

Analyses of cement materials in the vicinity of Harrisonburg, Va.

[Charles Catlett, analyst.]

	1	2	3	4
Lime oxide (CaO)	54.24	35.79	49.00	38.32
Magnesia (MgO)	.60	1.42	2.36	1.67
Oxides (R_2O_3)	.60	3.32	.70	1.58
Insoluble	2.08	27.06	7.00	25.24

1. Pure gray limestone from cut on Chesapeake and Western Railroad just east of crossing of Southern Railroad.
2. Calcareous slates exposed in cut on Chesapeake and Western Railroad just west of crossing of Southern Railroad.
3. Dark, friable limestones exposed at crossing of Chesapeake and Western and Southern railroads just south of Harrisonburg.
4. Calcareous slates from cut along Southern Railroad, 1½ miles north of Harrisonburg.

Mount Jackson and Newmarket.—Numerous exposures of argillaceous limestones may be seen in the foothills of Short Mountain several miles east of Mount Jackson, and also in the immediate vicinity of Newmarket. Practically the same thickness of rock is found here as that shown at Woodstock and vicinity, while the analysis of the rocks at both of these places indicates that in chemical composition at least they are similar to the best of Lehigh rock.

Analysis of Trenton limestone from near Mount Jackson, Va.

Calcium carbonate ($CaCO_3$)	70.00
Magnesium carbonate ($MgCO_3$)	2.00
Silica (SiO_2)	18.20
Oxides (R_2O_3)	8.00
Water (H_2O)	3.00

Western edge of valley north of Staunton.—Most of the outcrops of the Trenton limestones along the western edge of this part of the valley are remote from railroads, so that in spite of the excellent rock shown at a number of places exploitation of these limestones is not possible at present. Furthermore, throughout a considerable portion of this region the argillaceous limestones are cut out by overthrust faulting, the magnesian limestones resting upon the shales or still higher formations. But a single area can be mentioned in which the

cement rocks are exposed within a reasonable distance of a railroad. Several miles north of Stokesville, the terminus of the Chesapeake and Western Railroad, and a few miles south of Little North Mountain good outcrops of the rock are encountered. These limestones occur here in quantity and quality favorable to cement making, and as the railroads are near at hand the rock will undoubtedly prove to be of economic importance. Shales are available for mixture with the cement rock when its percentage of lime is too high, and pure limestones to increase this percentage when necessary are found in the valley just east of this point in sufficient quantity, so that, even with the present facilities, this is one of the most promising cement localities in the valley.

The composition of an average sample of this rock is shown by the following analysis:

Analysis of Trenton limestone from exposure several miles north of Stokesville, Va.

Calcium carbonate ($CaCO_3$)	73.14
Magnesium carbonate ($MgCO_3$)	2.90
Silica (SiO_2)	14.34
Oxides (R_2O_3)	6.49
Water (H_2O)	4.00

Mount Sidney and vicinity.—From Staunton to Mount Sidney and thence for several miles northeastward the Valley Branch of the Baltimore and Ohio Railroad either closely parallels or cuts through the belt of argillaceous limestones brought up on the western flank of the Massanutten Mountain syncline. The same rocks reappear on the eastern flank, 3 to 4 miles distant. The intervening country is occupied by Martinsburg shales, all of the younger rocks found on Massanutten Mountain having been removed by erosion. The favorable composition of the rock and the proximity of these two belts to railroads, the western to the Baltimore and Ohio, as mentioned above, and the eastern to the Shenandoah Valley Railroad, make them worthy of attention. The following analysis of specimens from the eastern belt in the vicinity of Weyers Cave shows more magnesia than the average:

Analysis of Trenton limestone from near Weyers Cave, Va.

Calcium carbonate ($CaCo_3$)	69.72
Magnesium carbonate ($MgCo_3$)	4.69
Silica (SiO_2)	14.62
Oxides (R_2O_3)	6.90
Water (H_2O)	3.94

Staunton.—East and northeast of this place the Trenton limestones are well developed and, together with the shales and pure limestones near by, offer abundant raw materials for the manufacture of cement. The railroad facilities at Staunton are exceptionally good, for a plant

here could obtain coal and ship its products over several lines. Ordinarily coal could be had on the most favorable terms over the Chesapeake and Ohio, but in times of labor disturbances in the New River field, coal could still be obtained from the Fairmont region. The Trenton limestones in the vicinity of Staunton as a rule run unusually high in lime, so that it will be necessary to mix shales or clays with them. Unlimited quantities of shales occur with the limestones, but deposits of good clays are not so common. The shales in the lower part of these beds are unusually calcareous, as the following analyses show, but those in the higher part of the series contain only a very small percentage of lime.

Analysis of shales in the vicinity of Staunton, Va.

[Charles Catlett, analyst.]

	1	2	3
Lime (CaO)	35.87	37.05	36.42
Magnesia (MgO)	.94	1.72	1.08
Silica (SiO_2)	23.08	19.92	19.28
Oxides (Al_2O_3, Fe_2O_3)	10.08	10.76	9.86
Ignition (CO_2)	....	....	31.70

Lexington.—Lexington is favorably placed for cement manufacture, for it is situated in the midst of a broad area of argillaceous limestones. In this part of the valley the Trenton limestones have been closely folded and overturned to the west, so that they show an extraordinary thickness. Occasionally the core of an anticline or syncline may be noted, and whenever it is possible to make accurate measurements the thickness of the limestones is found not to exceed 350 feet. This rock is theoretically of proper composition to make a high-grade Portland cement, but, as noted by Catlett, it is a question whether the relatively high ratio of silica to iron and alumina, tending to increase the refractory character of the clinker, is offset by the finely divided condition and intimate mixing of the natural material. The following analyses show variations in the composition of this rock.

Analyses of Trenton limestone, Lexington, Va.

[Charles Catlett, analyst.]

	1	2	3	4	5	6
Silica (SiO_2)	0.73	9.31	11.86	12.92	17.42	22.60
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	.79	3.47	1.76	3.88	4.70	7.06
Lime (CaO)	53.71	46.30	46.64	45.14	42.44	36.72
Magnesia (MgO)	.83	.86	.74	1.37	1.68	1.69
Ignition	....	....	38.82	37.20	35.62	32.52

PORTLAND CEMENT INDUSTRY IN VIRGINIA.

One plant is in operation in Virginia, that of the Virginia Portland Cement Company, at Craigsville. The materials used are limestones and shales of Lewistown (lower Helderberg) age. Analyses of these materials follow, quoted from the Cement Industry.

Analyses of cement materials used at Craigsville, Va.

	Limestone.	Shale.
Silica (SiO_2)	n. d.	53.63
Alumina (Al_2O_3) Iron Oxide (Fe_2O_3)	n. d.	24.47
Lime (CaO)	54.30	5.94
Magnesia (MgO)	.66	1.79
Carbon dioxide (CO_2) Water	43.63	10.03

PORTLAND-CEMENT RESOURCES OF WASHINGTON.

The geology of the State of Washington is not sufficiently well known to permit a very detailed statement regarding its cement resources. It must therefore be borne in mind that deposits of limestone available for Portland-cement manufacture, in addition to those discussed below, may exist in parts of the State which have not been carefully surveyed.

Limestones are known to occur in large quantity in two widely separated areas in Washington, and it is from these two areas that the State's principal supplies of limestone (and marble) for building, lime burning, and cement are now being obtained. The two areas are: (1) The San Juan Islands in northwestern Washington and (2) Stevens County in northeastern Washington.

SAN JUAN ISLANDS.

Large limestone deposits, probably of Cretaceous age, occur on various islands of the San Juan group, in the Strait of Juan de Fuca. These limestone beds are surrounded by igneous rocks, by which the limestones have been metamorphosed, occurring in consequence in the form of crystalline limestone or marble.

The limestone deposits on these islands vary greatly in size. The largest bed known is that of the Roche Harbor Lime Works, on San Juan Island. This extends[a] all the way across the peninsula from

[a] Ann. Rept. Washington Geol. Survey for 1901, pt. 3, p. 25.

Roche Harbor to Westcott Bay, a distance of half a mile. The width of the belt, as exposed at the outcrop, is 850 feet, and its average thickness above water level is 250 feet. This deposit is now extensively worked, the product being used both for lime burning and for smelter flux. An analysis[a] of the limestone gave the following result:

Analysis of limestone, Roche Harbor Lime Works quarry.

Silica (SiO_2)	0.25
Alumina (Al_2O_3) Iron oxide (Fe_2O_3)	.80
Lime carbonate ($CaCO_3$)	98.85

Other smaller deposits of limestone occur on various islands of the San Juan group. One of these deposits, located on the west coast of San Juan Island, about 7½ miles from Friday Harbor, now supplies material for a 2-kiln lime plant. On Orcas Island, near East Sound and Deer Harbor, similar deposits exist, and several are being worked, the product being burned into lime by two 1-kiln lime plants.

NORTHEASTERN WASHINGTON.

The Okanogan Highlands of northeastern Washington are largely made up of a series of crystalline rocks, most of which are of unknown age and origin. At various points in this crystalline area, particularly in portions of Stevens County, deposits of crystalline limestone or marble occur. The age of these limestones is not certainly known, but it is supposed that they are, in part at least, Carboniferous.

A number of these deposits have been worked as marble quarries, and a considerable amount of beautiful material is annually obtained from them. The deposits are of equal, or perhaps even of greater, value as sources of Portland-cement material, for rocks that are too much jointed and seamed to furnish decorative stone, or are of unsatisfactory color, will be available for cement plants.

Some of these rocks carry a high percentage of magnesium carbonate or else contain a large proportion of various silicate minerals. These are, of course, worthless as cement materials. A large proportion of them are, however, very low in magnesia, and can be considered available for Portland-cement material. A few of them, according to reports, carry a large percentage of argillaceous matter, thus approaching in composition the Lehigh "cement rock" of Pennsylvania and New Jersey.

[a] Ann. Rept. Washington Geol. Survey for 1901, pt. 3, p. 25.

Analyses of limestones (marbles) of Stevens County, Wash.[a]

	1	2	3	4	5	6	7	8
Silica (SiO_2)	0.87	3.49	0.98	0.82	2.61	3.12	0.13	1.00
Alumina (Al_2O_3)	.00	.00	.00	.00	.00	.00	.00	.00
Iron oxide (Fe_2O_3)	.00	.24	Tr.	Tr.	.00	.93	.00	.00
Lime (CaO)	55.16	51.54	53.96	54.81	53.68	52.04	54.95	53.96
Magnesia (MgO)	.21	1.11	1.25	1.70	.76	.67	.54	1.60
Carbon dioxide (CO_2)	43.77	42.46	43.76	43.56	42.89	43.22	44.22	43.27

1. White marble, Jefferson Marble Company quarries, 15 miles northwest of Colville.
2. Pink marble, Jefferson Marble Company quarries, 15 miles northwest of Colville.
3. White marble, Keystone Marble Company quarries, 16 miles north of Colville.
4. Gray marble, Keystone Marble Company quarries, 16 miles north of Colville.
5. White marble, Colville Marble Company quarries, 16 miles northeast of Colville.
6. Dark-gray marble, Colville Marble Company quarries, 16 miles northeast of Colville.
7. Light-gray marble, 2¼ miles northwest of Bossbury.
8. Florentine Marble Company, Ryan.

PORTLAND-CEMENT RESOURCES OF WEST VIRGINIA.

PORTLAND-CEMENT MATERIALS.

Four limestone horizons are worth considering as possible sources of cement material in West Virginia. These are, in geological order:

4. Coal Measures (Pennsylvania) limestones.
3. Greenbrier (Mississippian) limestone.
2. Lewiston (lower Helderberg) limestone.
1. Ordovician limestones (Trenton, etc.).

Of these the Greenbrier and the Ordovician limestones are by far the most important in this connection. All of these limestones are shown on the map (Pl. XV).

ORDOVICIAN LIMESTONES.

Nonmagnesian limestones occur at several horizons in the Ordovician, the most important from the present point of view being of Trenton age. These correspond geologically to the cement rock of the Lehigh district of Pennsylvania. In West Virginia they are extensively developed in the Shenandoah Valley.

At and near Martinsburg, Berkeley County, this pure limestone has been extensively quarried for flux. The developments at this point have been recently reported[b] on by Mr. G. W. Stose, as follows:

At Martinsburg, W. Va., this limestone is exceptionally pure and very thick. It has been quarried there on a vast scale by the Standard Lime and Stone Company for use as flux in the iron furnaces about Pittsburg.

[a] These analyses were obtained from the report by Professor Shedd on "The building and ornamental stones of Washington," contained in the Annual Report of the Washington Geol. Survey for 1902, pp. 3–163. This report contains detailed descriptions of the various quarry areas, and is therefore valuable for reference in the present connection.

[b] Bull. U. S. Geol. Survey No. 225, pp. 516–517.

The limestone outcrops in a belt extending southward from the town. On the east side is a low ridge of Hudson shale containing graptolites of Utica age near the base. Dipping at an angle of 20 degrees under these beds are 90 feet of dark, compact, crystalline and shaly limestones bearing fossils of Trenton age. Below this are three or four heavy beds of pure limestone averaging 15 to 20 feet in thickness, with a total of about 80 feet. This is the deposit that is quarried. The upper bed is a very massive, compact, light-gray limestone, weathering chalky white on the surface, with smooth fracture and but slight indications of bedding. The lower beds are darker, coarser grained, not so homogeneous, and have a rough fracture, and at the base are thinner bedded. The only fossils observed in these beds are a few *Leperditia* found in the upper layers, indicating Lowville (Birdseye) age.

The whole of this mass is quarried, and is stated to average 98 per cent carbonate of lime. The two samples tested by the Geological Survey contained 96.2 and 97.7 per cent. The limestone is quarried in an open cut 200 to 250 feet wide and 80 to 100 feet deep, the workable depth depending upon the amount of stripping that is profitable. The open cut extends for over 1½ miles along the strike and is being worked along its entire length. The same beds apparently continue beyond, to the south, and there is every reason to believe that they also occur along the strike north of the town. The rock is taken out on tram cars, is crushed to 5-inch size, and is loaded directly into the railway cars on the track. The reason that the stone can be profitably shipped such a distance is that the cars which transport the coal from the Pennsylvania mines to the south return loaded with limestone, thus avoiding an empty return run, and the freight rates are reduced to a minimum. It is reported that from 20 to 50 carloads a day of the crushed rock are shipped. With a quarry face of 80 feet and the dip of the rocks 20 degrees, the estimated output of the quarry per mile is about 3,000,000 tons.

An analysis by Rogers[a] is given below. It is of a specimen from a point 4 miles from Harpers Ferry, on the road to Martinsburg.

Analysis of limestone from near Harpers Ferry, W. Va.

Silica (SiO_2)	1.83
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	.85
Lime carbonate ($CaCO_3$)	95.86
Magnesian carbonate ($MgCO_3$)	1.46

LEWISTON (LOWER HELDERBERG) LIMESTONE.

The Lewiston limestone, although occurring in West Virginia, is not so available a source of cement material as the Trenton and Greenbrier limestones. The only obtainable analysis of rock from this location is given below, quoted from Rogers. The specimen analyzed was from Pattersons Creek, near Hampshire Furnace.

[a] Geology of the Virginias, p. 170.

Analysis of limestone from Pattersons Creek, West Virginia.

Silica (SiO_2)	4.96
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	.76
Lime carbonate ($CaCO_3$)	92.44
Magnesian carbonate ($MgCO_3$)	1.40
Water	.52

GREENBRIER LIMESTONE.

As shown on the accompanying geological map the Greenbrier (Mississippian or Lower Carboniferous) limestone is well developed in West Virginia, reaching its maximum thickness in its type area in Greenbrier County. At Manheim, on Cheat River, east of Grafton, this limestone is now used by the Buckhorn Portland Cement Company.

Throughout its entire range the Greenbrier limestone is mainly a very pure nonmagnesian limestone, though occasionally shaly or magnesian beds occur. Because of its thickness, its favorable composition, and its location with respect to fuel supplies and transportation routes, it is a very promising source of Portland cement material.

Analyses of Greenbrier limestone, West Virginia.

	1	2	3	4	5	6	7	8	9	10	11
Silica (SiO_2)	0.97	19.87	6.20	1.88	6.04	0.40	5.80	27.00	7.24	6.00	26.96
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	1.46	4.09	1.20	.56	.88	.48	1.16	.88	2.52	1.52	1.60
Lime carbonate ($CaCO_3$)	96.46	74.56	89.92	95.92	89.44	98.20	89.76	67.40	88.32	88.52	64.00
Magnesium carbonate ($MgCO_3$)	1.11	1.95	Tr.	Tr.	2.80	.....	2.32	2.32	.....	3.24	6.76
Water	n. d.	n. d.	.44	.40	.84	.24	.92	.56	.72	.72	.68

1. Huddleston quarry, Snow Flake, Greenbrier County. J. B. Britton, analyst. Twentieth Ann. Rept. U. S. Geol. Survey, pt. 6, p. 460.
2. Shavers Mountain, Randolph County. E. Whitfield, analyst. Bull. U. S. Geol. Survey No. 27, p. 74.
3. Near Red Sulphur Springs, Monroe County. Rogers, "Geology of the Virginias," p. 396.
4. Near Union, Monroe County. Rogers, "Geology of the Virginias," p. 397.
5. Two miles south of Kingwood, Preston County. Rogers, "Geology of the Virginias," p. 398.
6. Muddy Creek Mountain, near Blue Sulphur Springs. Rogers, "Geology of the Virginias," p. 396.
7, 8. Cheat River, below Gum Camp Run, Preston County. Rogers, "Geology of the Virginias," p. 397.
9. East side Laurel Hill, Monongalia County. Rogers, "Geology of the Virginias," p. 397.
10. Front ridge, opposite Petersburg, Tucker County. Rogers, "Geology of the Virginias," p. 398.
11. East side Briery Mountain, Preston County. Rogers, "Geology of the Virginias," p. 398.

COAL MEASURES (PENNSYLVANIAN) LIMESTONES.

As in Pennsylvania and Ohio, thin limestone beds occur at many horizons in the Coal Measures of West Virginia. These limestones are usually low in magnesia, but are also quite low in lime carbonate, commonly ranging from 80 to 90 per cent in that constituent. As

Portland-cement materials their value depends entirely upon their nearness to fuel supplies, for they are neither thick enough nor pure enough to compare favorably under equal conditions with the Greenbrier or Trenton limestones.

Analyses of Coal Measures limestones, West Virginia.

	1	2	3	4	5	6	7	8	9	10
Silica (SiO_2)	10.24	10.88	13.28	32.04	0.92	10.33	1.53	1.60	7.20	1.76
Alumina (Al_2O_3), Iron oxide (Fe_2O_3)	3.52	1.92	1.68	7.00	.96	.90	.96	1.60	2.00	.80
Lime carbonate ($CaCO_3$)	81.40	86.80	84.40	56.48	95.52	[85.75]	[95.10]	96.20	89.72	83.92
Magnesium carbonate ($MgCO_3$)	3.32	Tr.	Tr.	2.48	1.88	[2.26]	[1.95]	Tr.	Tr.	2.80
Water	1.24	.60	.64	2.00	.76	.05	.10	.60	1.08	.72

1. Two and one-half mile southeast of Kingwood. Rogers's "Geology of the Virginias," page 400.
2, 3. Ten Mile Creek, 1 mile from mouth, Kanawha County. Rogers's "Geology of the Virginias," page 524.
4. Hughes Creek, Kanawha County. Rogers's "Geology of the Virginias," page 400.
5. Clarksburg. Rogers's "Geology of the Virginias," page 401.
6, 7. Moundsville Narrows, 12 miles below Wheeler. Bull. U. S. Geol. Survey, No. 9, page 17.
8, 9, 10. Two Mile Creek, Kanawha County. Rogers's "Geology of the Virginias," page 525.

PORTLAND CEMENT INDUSTRY OF WEST VIRGINIA.

West Virginia has at present only one Portland-cement plant. This is the mill of the Buckhorn Portland Cement Company, located on the Cheat River at Manheim.

The materials used are the Greenbrier limestone, shales of the same series, and Quaternary clays from the river flats. Analyses of these materials, by R. L. Humphrey, follow, and are quoted from Engineering News, volume 50, page 409.

Analyses of cement materials, Manheim, W. Va.

	Limestone.			Shale.	Clay.
	Lower.	Middle.	Upper.		
Silica (SiO_2)	23.40–20.20	18.60–13.08	8.84– 2.92	62.74	68.16
Alumina (Al_2O_3), Iron oxide (Fe_2O_3)	9.10– 8.80	7.60– 6.12	5.04– 1.82	19.40	16.18
Lime carbonate ($CaCO_3$)	60.31–68.89	72.27–80.09	85.00–94.00	.38	.42
Magnesium carbonate ($MgCO_3$)	Tr.	Tr.– .61	.72– 1.10	1.41	1.04

PORTLAND CEMENT RESOURCES OF WISCONSIN.

ORDOVICIAN AND SILURIAN LIMESTONES.

The Ordovician and Silurian deposits in Wisconsin contain heavy and widely distributed beds of limestone. It is necessary, however, to warn the prospector that the chances for obtaining a well-located limestone sufficiently low in magnesia to be serviceable for this use seem to be very poor. Of the numerous analyses of Wisconsin limestones that have been examined by the writer, only three show a limestone carrying less than 30 per cent of magnesium carbonate. Low-magnesia limestones exist in the State, but the chances seem to be against securing a satisfactory deposit of such material. So far as known, the only fairly thick and extensive bodies of low-magnesia limestone in Wisconsin occur in the lead region in the upper part of the Platteville limestone,[a] heretofore referred to the Trenton series.

Mr. E. O. Ulrich states that in the southwestern part of the State a generally thin and rather locally developed bed of relatively pure limestone forms the top of the Platteville. The "glass rock," as this bed is called, is probably better developed at Mineral Point and Platteville, Wis., than anywhere else in the lead district. At these localities it is filled with a highly characteristic fauna of late Stones River age. The rocks deposited upon it—the Galena limestone—are Black River and Trenton in age.

Farther east, as at Beloit, and thence northward to Escanaba, Mich., the "glass rock" is not represented in the sections. The "upper buff" and "blue," however, occur continuously east and north of Janesville and Beloit, Wis., while they are wanting, at least locally, in the lead region. Both the "upper buff and blue" probably—the latter certainly—represent a horizon intermediate between the lowest Galena and the "glass rock."

Grant[b] has recently described this particular limestone as follows:

> The "glass rock" belongs near the top of the Trenton limestone. This term has been applied to a number of varieties of limestone in this general horizon. It may be said that the name is used for very fine grained, compact, and hard beds of limestone which occur near the top of the Trenton. This is about as accurate a general definition of the term as can be given. There is, however, one particular phase of this rock which may be called the typical glass rock and which is apparently the rock to which the name was first applied. This is a very fine grained, very compact limestone, which breaks with a conchoidal fracture and which when fresh is of a light-brown or chocolate color. On exposure to the air, however, this color changes to a bluish gray. This phase of the glass rock is found in many places throughout the western two-thirds of the lead and zinc district. It usually occurs in thin beds, and in some places, especially at Platteville, is an important building material, the normal school building at this place and one of the high school buildings being constructed almost

[a] Bain, H. F., Zinc and lead deposits of northwestern Illinois: Bull. U. S. Geol. Survey No. 246, 1905, pp. 18-20.

[b] Grant, U. S., Geol. Wisconsin, vol. 2, p. 681, 1877.

entirely of this rock. The fact that it does not occur in thicker beds prevents its universal use as a building stone. Very frequently this glass rock is packed full of fossils. It is a comparatively pure limestone, containing only a small amount of magnesia, the chief impurities being silica and clay.

The composition of this rock is shown by the following analyses.

Analyses of Platteville limestones, Wisconsin.

	1	2	3
Silica (SiO_2)	1.10	6.16	7.03
Alumina (Al_2O_3)		2.26	2.21
Iron oxide (Fe_2O_3)		1.90	1.22
Lime carbonate ($CaCO_3$)	97.92	85.54	84.02
Magnesium carbonate ($MgCO_3$)	1.60	3.98	5.33
Water	n. d.	.93	.61

1. Near Benton, on the Fever River, Geol. Wisconsin, vol. 2, pp. 560-561.
2. Mineral Point, Geol. Wisconsin, vol. 2, pp. 560-561.
3. Bristol, Dane County, Geol. Wisconsin, vol. 2, pp. 560-561.

QUATERNARY SHELL MARLS.

As in Michigan, Ohio, New York, and other States north of the glacial limits, many lakes occur in Wisconsin, and some of these contain deposits of marl. Little attention has yet been paid to these marl deposits and practically nothing can be said as to their occurrence and character. One noteworthy feature, however, should be borne in mind. As already shown, almost all of the limestone deposits of the State are highly magnesian. As the marls are ultimately derived from local limestones, it is to be expected that Wisconsin marls will carry larger percentages of magnesia than marls occurring in areas of pure limestones. This seems to be indicated by the following analysis:

Analysis of shell marl, Wisconsin.

Silica (SiO_2)	1.48
Alumina (Al_2O_3)	.19
Iron oxide (F_2O_3)	
Lime carbonate ($CaCO_3$)	86.09
Magnesium carbonate ($MgCO_3$)	7.18
Sulphur trioxide (SO_3)	.44
Water	1.67
Organic matter	.952

Sections 17, 18, 19, and 20; town of Pierce, T. 24, R. 25. Kewaunee County. G. Bode, analyst. Geology of Wisconsin, vol. 2, p. 239.

PORTLAND-CEMENT RESOURCES OF WYOMING.

Limestones are extensively distributed throughout the State of Wyoming, but little attention has yet been paid to their economic value. The following analyses may prove serviceable in locating deposits that may be of use for lime or cement making:

Analyses of limestones, Wyoming.

	1	2	3	4	5	6	7	8	9
Silica (SiO_2)	2.02	22.22	31.28	31.45	23.49	23.47	6.49	1.52	0.43
Alumina (Al_2O_3)	.57	.21	1.83	1.58	6.17	6.27	......	......	.10
Iron oxide (Fe_2O_3)			.22	.21	2.16	2.20	.37	.31	.12
Lime (CaO)	54.06	43.24	34.20	34.18	33.79	33.83	54.16	54.18	55.34
Magnesia (MgO)	.34	.15	.11	.08	.62	.74	.15	.15	.21
Alkalies (K_2O, Na_2O)	n. d.	n. d.	.51	.61	.38	.38	n. d.	n. d.	n. d.
Carbon dioxide (CO_2)	42.85	33.94	26.79	26.82	27.08	27.03	43.68	43.69	43.73
Water	.42	.14	4.64	4.64	6.27	6.20			.05

1. Vermilion Creek Canyon. Upper Coal Measures.
2. Near Red Buttes. Jurassic?
3, 4. Turtle Bluffs, north side of Henrys Fork. Eocene.
5, 6. Green River City. Eocene.
7, 8. Five miles south of Cheyenne. Pleicene.
9. Three miles east of Laramie. Carboniferous.

Analyses 1-8 by B. E. Brewster, Rept. U. S. Geol. Expl. 40th par., vol. 2; analysis 9 from Report Territorial Geologist for Wyoming for 1888-89, p. 73.

PART III. NATURAL-CEMENT RESOURCES OF THE UNITED STATES.

INTRODUCTION.

On the following pages an attempt will be made to discuss the natural cements as a class, emphasis being laid upon the points of resemblance of the various brands, their many points of difference being for a time disregarded. The difficulties encountered in such an attempt are greater than the reader at first sight may imagine, for few engineers realize what a heterogeneous collection of products is included under the well-known name of "natural cement." This lack of knowledge is easily explained. Under ordinary circumstances, natural cements are too low in value to be shipped far from their points of production. The natural cement made at any given locality has usually, therefore, a well-defined market area, within which it is well known and subject to little competition. The engineer practicing within such an area forms his idea of natural cements in general from what he knows of the brands encountered in his work, and as all the brands from one cement-producing locality are apt to resemble one another closely he is likely to conclude that natural cements form a homogeneous class, with many points of resemblance and few of difference. On the contrary, there may be as much difference in strength, rate of set, composition, etc., between natural cements from two different localities as between any given brand of natural cement and a Portland cement.

DEFINITION OF NATURAL CEMENTS.

The term "natural cements" is here used to include all cements produced by burning a natural limestone rock without previous grinding or mixing. As so used it includes the class of doubtful products commonly known as "natural Portlands," which are so largely made in France and Belgium. The reasons for including these "natural Portlands" with the natural cements instead of with the true Portlands are stated in considerable detail on pages 21–23.

Natural cements are produced by burning a natural clayey limestone, containing 15 to 40 per cent of silica, alumina, and iron oxide, without preliminary mixing and grinding. This burning takes place at a temperature that is usually little, if any, above that of an ordinary lime-kiln. During the burning the carbon dioxide of the limestone is

almost entirely driven off, and the lime combines with the silica, alumina, and iron oxide, forming a mass containing silicates, aluminates, and ferrites of lime. In case the original limestone contained any magnesium carbonate the burned rock will contain a corresponding amount of magnesia and magnesian compounds.

The burned mass will not slake if water be poured on it. It is necessary, therefore, to grind it rather fine; after it is ground, if the resulting powder (natural cement) be mixed with water, it will harden rapidly. This hardening or setting will take place either in air or under water.

RELATIONS OF NATURAL CEMENTS TO OTHER CEMENTS.

Natural cements differ from ordinary limes in two very noticeable ways: (1) The burned mass does not slake when water is poured on it. (2) Natural cement powder has hydraulic properties; i. e., if properly prepared it will set under water.

Natural cements are closely related to hydraulic limes on the one hand and to Portland cement on the other, agreeing with both in the possession of hydraulic properties. They differ from hydraulic limes, however, in that the burned natural cement rock will not slake when water is poured on it.

Natural cements differ from Portland cements in the following important particulars: (1) Natural cements are made by burning masses of natural rock, not by burning carefully prepared and finely ground artificial mixtures. (2) Natural cements, after burning and grinding, are usually yellow to brown and light in weight, their specific gravity being about 2.7 to 2.9; Portland cement is commonly blue to gray in color and heavier, its specific gravity ranging from 3.0 to 3.2. (3) Natural cements are always burned at a lower temperature than Portland, and commonly at a much lower temperature, the mass of rock in the kiln never being heated high enough to even approach the fusing or clinkering point. (4) Natural cements set more rapidly than Portland cement, but do not attain so high ultimate strength. (5) Various brands of natural cements will show very great differences in composition, while Portland cement is a definite product whose percentages of lime, silica, alumina, and iron oxide vary only between narrow limits.

RAW MATERIAL (NATURAL-CEMENT ROCK).

The material used in the manufacture of natural cement is invariably a clayey limestone, carrying from 13 to 35 per cent of clayey material, of which 10 to 22 per cent or so is silica, while alumina and iron oxide together may vary from 4 to 16 per cent. These clayey materials give the resulting cement its hydraulic properties. Stress is often care-

lessly or ignorantly laid on the fact that many of the best-known natural cements carry large percentages of magnesia, but magnesia (in natural cements at least) may be regarded as being almost exactly interchangeable with lime, so far as the hydraulic properties of the product are concerned. The presence of magnesium carbonate in a natural-cement rock is then merely incidental, while the silica, alumina, and iron oxide are essential. The 30 per cent or so of magnesium carbonate which occurs in the cement rock of the Rosendale district, New York, could be replaced by an equal amount of lime carbonate and the burnt stone would still give a hydraulic product. If, however, the clayey portion (silica, alumina, and iron oxide) of the Rosendale rock could be removed, leaving only the magnesium and lime carbonates, the burnt rock would lose all of its hydraulic properties and would yield simply a magnesian lime.

This point has been emphasized because many writers on the subject have either explicitly stated or implied that it is the magnesian carbonate of the Rosendale, Akron, Louisville, Utica, and Milwaukee rocks that causes them to yield a natural cement on burning.

Since within very wide limits of composition any clayey limestone will give a natural cement on burning, it can readily be seen that satisfactory natural-cement materials must be widely distributed and of common occurrence. Hardly a State is entirely without limestones sufficiently clayey to be available for natural-cement manufacture. The sudden rise of the American Portland-cement industry, however, has acted to prevent any great expansion of the natural-cement industry. It would be difficult to place a new natural cement on the market in the face of competition from both Portland cement and from the older and well-established brands of natural cement. Such new natural-cement plants as have been started within recent years have mostly been located in old natural-cement districts, where the accumulated reputation of the district would help to introduce the new brand. The only exceptions to this rule, indeed, were the Pembina plant in North Dakota, the Rossville plant in Georgia, and a plant in the State of Washington. Of these, the Pembina plant was established with the intention of making Portland cement, but the raw materials soon proved to be unsuitable and the plant was converted. The plant in Washington is located in an area where any kind of cement is readily salable. The Rossville plant was built by an Akron, N. Y., cement manufacturer to utilize a peculiarly satisfactory natural-cement rock.

METHODS OF MANUFACTURE.

The manufacturing methods at a natural cement plant are of the simplest kind, including merely the burning of the cement rock and the pulverizing of the product,

The burning is carried on in vertical kilns, closely resembling lime kilns in shape, size, etc. The limestone and fuel are usually fed into the kiln in alternate layers, though at a few plants more advanced types of kilns are in use. The burned product is crushed and then reduced to powder, commonly in buhrstone mills. Recently advances have been made in crushing practice, and several plants now reduce their product in tube mills. The manufacturing processes have been purposely stated briefly here, because further details concerning them will be found in the descriptions of the various natural-cement producing districts, which follow.

NATURAL-CEMENT RESOURCES OF GEORGIA.

Two natural cement plants located in northwest Georgia use cement rocks from two different geological formations.

The plant of the Chickamauga Cement Company is located at Rossville, Ga., a few miles south of Chattanooga. The slaty material used is a thin-bedded raw limestone of the Chickamauga (Ordovician) age, which is here exposed over a considerable area. In geologic age, as well as in chemical composition, this rock is closely similar to the cement rock of the Lehigh district of Pennsylvania. The rock is quarried and carried up to four vertical sheet-iron kilns of a patented (Cummings) design, fired with coal. The burned rock is sent through a Cummings vertical crusher, and then finally reduced under three runs of 42-inch Esopus millstones.

The product is marketed under the brands of Dixie (natural) and New South ("Portland"). It is, of course, all a natural cement, according to present-day definitions of Portland cement, as it is not artificially mixed prior to burning, and the burning is conducted at too low a temperature to give a true Portland. That a real Portland cement could, however, be readily made from some of this material is proved by the following analysis of the burned product. This analysis, by Cummings, is quoted from the Twenty-first Annual Report of the United States Geological Survey, part 6, page 410:

Analysis of cement rock from Rossville, Ga.

Silica (SiO_2)	22.17
Alumina (Al_2O_3)	8.20
Iron oxide (Fe_2O_3)	2.50
Lime (CaO)	65.68
Magnesia (MgO)	1.45

The Conasauga formation of the Cambrian is described by Dr. C. W. Hayes as "normally composed, at the base, of thin limestones interbedded with shales, then of yellowish or greenish clay shales, and at the top of calcareous shales, grading into blue seamy limestones."

The Western and Atlantic Railroad, now operated under lease by the Nashville, Chattanooga and St. Louis system, crosses the outcrop

of these rocks from above Adairsville to within a mile of Kingston. At one point near the southern end of this belt limestone obtained from beds lying near the top of the Conasauga formation has long been utilized in the manufacture of natural cement at the plant of the Howard Hydraulic Cement Company, at Cement, Bartow County, Ga., about 2 miles north of Kingston.

In the low ridge east of the railroad at Cement station, a section of these Conasauga limestones has been measured by Dr. J. W. Spencer.[a] The series shown, from the top down, was as follows:

Section near Cement Station, Ga.

	Feet.
Blue limestone	8
Slaty limestone (cement rock)	4
Blue limestone	6
*Argillaceous limestone	2
*Siliceous limestone (hydraulic)	4
*Siliceous limestone (cement rock)	7
Fine black limestone	12
Earthy limestone	3

When the plant was visited by the writer, in the fall of 1902, the three beds marked with asterisks were being worked for natural cement, and together constitute the "main cement bed" later mentioned in this article. Doctor Spencer quotes the following analyses, made by Mr. W. J. Land, of the cement rock:

Analyses of cement rocks from Georgia.

	1	2
Lime carbonate ($CaCO_3$)	43.50	55.00
Magnesium carbonate ($MgCO_3$)	26.00	26.10
Silica (SiO_2)	22.10	10.00
Iron oxide (Fe_2O_3)	1.80	2.00
Alumina (Al_2O_3)	5.45	6.10
Organic matter	.15	.50
Water	1.00	.30

The mill is located at the side of the railway, the farthest quarry being only a few hundred feet away. The main cement bed at the quarry now worked is about 15 feet thick. In common with the other beds it dips eastward at an angle of about 20°. It is overlain and underlain by limestone beds of various composition, but none fit for the manufacture of natural cement. A thinner cement bed lay about 8 feet above the bed now worked, but was worked out by stripping and quarrying over a considerable area early in the history of the plant.

[a] The Paleozoic group of Georgia, p. 100.

All the cement rock used is now obtained by mining. Two inclines have been run in on the dip of the beds. These inclines are, at and near their entrances, entirely in the cement bed, several feet of cement rock being left above and below them to serve as floor and roof. Farther in, however, the height of the passages is increased, and almost the entire thickness of the cement bed is taken out Pillars of cement rock are left at intervals to support the roof.

The cement rock is blasted out, sledged when necessary to a size convenient for the kilns, and loaded onto cars carrying about 1½ tons each. These cars run on narrow-gage tracks, which extend from near the heads of the workings to the kilns. As the grade in the inclines is heavy the cars are hauled out of the mine by wire cables, power being supplied by the crusher engine. Outside of the mine, however, the grade to the kilns is sufficiently light to permit the cars to be run by hand to the level from which the rock is fed to the kiln.

The kilns are of the familiar dome type commonly used in lime and natural-cement burning, and are six in number. Four are jacketed with steel and lined with fire brick, the space between the jacket and the lining being filled with clay. The two remaining kilns differ from these only in the fact that in place of the steel jacket their exterior surfaces are laid up with rock. These rock-jacketed kilns are said to be somewhat more satisfactory than those of the steel-jacketed type.

All the kilns are 25 feet in height, and have an output of 60 barrels of cement each. The kilns are charged to the top with fuel and cement rock, in the proportions of about 300 pounds fuel to 2,500 pounds rock. The fuel used is coal, the sizes being nut, pea, and slack, in about equal amounts. Seven or eight days are required, on the average, to "turn a kiln," including charging, burning, and drawing.

When the kilns are drawn the clinker is picked over and then carried by a Jeffreys elevator to pot crushers of special design. On issuing from the crushers the material encounters revolving screens of about ¼-inch mesh. All material that does not pass these screens is sent back to be recrushed. The finer material which passes through this ¼-inch screen meets another revolving screen of about 50 mesh. Everything that passes through this fine screen is sent direct by a conveyor to the packing machines, while the material failing to pass the 50-mesh screen is sent to buhrstone mills, where it is ground, screened, and sent to the packers.

The Howard cement is marketed as the "Red Keystone" brand, and is favorably known to the southern cement trade, having been extensively used in engineering work. It has certain properties which serve to differentiate it from other natural cements. In color it is lighter than any other natural cement known to the writer, the set cement being very light gray or yellowish gray. Its specific gravity

is low, so that cement barrels of the usual size will contain only about 240 pounds of Howard cement. Most of the product is, however, marketed in bags containing 80 pounds each. It is said not to stain masonry and to resist well the action of salt air and spray. Its final hardening is slow relative to the Louisville cements, and for this reason it does not show up well in short-time comparative tests for tensile strength, though at periods longer than a month it gives excellent results.

The Howard cement is high in both lime and magnesia, compared with the Louisville cements. Two analyses are given below, the first quoted in Cummings's American Cements and the second by W. M. Bowron. To these have been added the average of five analyses of typical Louisville cements.

Analyses of natural cements.

	Howard cement.		Average Louisville cement.
	1	2	
Silica (SiO_2)	22.58	19.60	23.72
Alumina (Al_2O_3)	7.23	11.60	8.51
Iron oxide (Fe_2O_3)	3.35		
Lime (CaO)	48.18	48.86	43.57
Magnesia (MgO)	15.00	18.14	9.26

NATURAL-CEMENT RESOURCES OF ILLINOIS.

Three natural-cement plants, operated by two companies, are now working in Illinois, near Utica, La Salle County. The rock used is a limestone belonging to the so-called "Lower Magnesian" group of early western geologists. It is of Ordovician age and underlies the St. Peters sandstone.

The section exposed in the neighborhood of the Utica cement plants is as follows, from the top downward:

Section of cement rock beds exposed at Utica, Ill.

	Feet.
Cement rock	7
Limestone	16–22
Cement rock	6
Sandstone	2–4
Cement rock	5

Of the three cement rock beds shown in this section, the uppermost bed gives a very quick-setting cement while the two lower beds furnish products of much slower set.

Analyses of natural-cement rocks, Utica, Ill.

	1	2	3	4	5
Silica (SiO_2)	12.22	17.01	21.00	21.12	14.15
Alumina (Al_2O_3)	9.39	3.35			6.37
Iron oxide (Fe_2O_3)	3.90	2.39	2.00	1.12	2.35
Lime (CaO)	24.40	32.85	24.36	23.66	26.32
Magnesia (MgO)	10.43	8.45	14.31	15.22	12.10
Alkalies (K_2O, Na_2O)	n. d.	n. d.	.18	n. d.	[a].18
Sulphur trioxide (SO_3)	n. d.	1.81	n. d.	n. d.	1.81
Carbon dioxide (CO_2)	38.48	34.12	34.90	35.35	34.70
Water			3.00	1.07	2.03

[a] Far too low; true value is probably over 4 per cent.

1. F. W. Clarke, analyst. Sample collected by E. C. Eckel.
2. C. Richardson, analyst. Brickbuilder, July, 1897.
3. Blaney & Mariner, analysts. Quoted by Worthen, Geology of Illinois, vol. 1, p. 151.
4. Blaney, analyst. Trans. Am. Inst. Min. Eng., vol. 13, p. 180.
5. Average of preceding four analyses.

The kilns in use in the Utica district in Illinois are elliptical in cross section (plan) with vertical walls. The largest kilns of this type are 30 feet in their longest inside diameter and 12 feet wide. Their total height, with foundation, is 50 feet, giving a clear height of 45 feet from bottom of draw hole to top of kiln. These kilns turn out 400 barrels (265 pounds each) of cement a day, taking 18 to 20 pounds of coal per barrel of cement. This corresponds to a fuel consumption of only 6.8 to 7.5 per cent.

The second size of Utica kilns is 20 feet by 9 feet in its inside diameters. The smallest size is, like the others, elliptical, with inside diameters of 14 and 7 feet, respectively, and a height of 32 feet from top of bridge wall to top of kiln. These kilns turn out 300 to 375 barrels per day.

All the diameters quoted above are internal measurements. The kiln shell proper is of one-fourth-inch sheet iron. This is lined, successively, with an 18-inch layer of ashes, 18 inches of stone or common brick, and 9 inches of fire brick.

Analyses of natural cements, Utica, Ill.

	1	2	3	4	5
Silica (SiO_2)	19.89	27.60	34.66	35.43	29.39
Alumina (Al_2O_3)	11.61	10.60	5.10	9.92	9.04
Iron oxide (Fe_2O_3)	1.35	.80	1.00		1.05
Lime (CaO)	29.51	33.04	30.24	33.67	31.61
Magnesia (MgO)	20.38	17.26	18.00	20.98	19.15
Alkalies (K_2O, Na_2O)	5.96	7.42	6.16	n. d.	6.51
Carbon dioxide (CO_2) / Water	n. d.	2.00	4.84	n. d.	3.42

1. Haas and McGraw, analysts. Engineering News, April 30, 1896.
2, 3. Quoted by Cummings. American Cements, p. 36.
4. J. V. Blaney, analyst. Trans. Am. Inst. Min. Eng., vol. 13, p. 180.
5. Average of preceding four analyses.

NATURAL-CEMENT RESOURCES OF INDIANA AND KENTUCKY.

The plants of the "Louisville district" are mostly located in Indiana, though one or two mills are in operation on the Kentucky side of the Ohio River. The rock is a fine-grained, clayey limestone of the Devonian age. In color it varies from light drab to dark or bluish drab, when fresh, weathering to a dull buff on long exposure. The cement bed varies from 10 to 16 feet in thickness in the different quarries.

Analyses of natural-cement rock, Louisville district, Indiana–Kentucky.

	1	2	3	4	5	6
Silica (SiO_2)	9.69	9.80	13.65	15.21	18.33	13.36
Alumina (Al_2O_3)	2.77	2.03	3.46	4.07	4.98	3.46
Iron oxide (Fe_2O_3)	1.95	1.40	1.45	1.44	1.67	1.58
Lime (CaO)	29.09	29.40	34.55	33.99	30.41	31.49
Magnesia (MgO)	15.69	16.70	7.97	7.57	8.04	11.19
Carbon dioxide (CO_2)	40.14	41.49	35.92	35.03	32.76	37.07

Analyses 1 to 5, inclusive, are by W. A. Noyes. Quoted by Siebenthal, Twenty-fifth Ann. Rept. Indiana Dept. Geol. Nat. Res., pp. 380–386.

1. Hausdale mill, New Albany Cement Company; used for "Crown" brand.
2. Ohio Valley mill, Ohio Valley Cement Company; used for "Fern Leaf" brand.
3. Falls City mill, Union Cement and Lime Company; used for "Diamond" brand.
4. Speed mill, Louisville Cement Company; used for "Star" brand.
5. Black Diamond mill, Union Cement and Lime Company; used for "Black Diamond" brand.
6. Average of the preceding five analyses.

Two styles of kiln are in use in the Louisville district. The older and smaller kilns are 36 feet in height, 8 feet in diameter at the top, enlarging to 12 feet at a point 24 feet above the base, and again contracting to 4 feet at the base. These are drawn from a chute by use of a swinging gate or apron. Coal and rock are charged in alternate layers. About a week suffices for the passage through the kiln of any particular mass of material. These small kilns produce about 100 to 125 barrels (265 pounds each) of cement a day.

The larger kilns are 54 feet from extreme base to top. Viewed from the outside they appear to be cylinders 54 feet high and 16 feet in diameter. Their interior space, however, is 10 feet in diameter at the top, enlarging to 12 feet at a point 18 feet above the base. Below this level, though the interior walls still slope outward, the space is really contracted by the occurrence of a conical mass of brickwork in the center of the kiln. This cone throws the downcoming clinker toward the draw gates at the sides. A 9-inch lining of fire brick is set around the kiln space proper. This is followed by 9 inches of common brick, and the space between the common brick lining and the exterior kiln

shell (which is one-fourth inch iron) is filled with clay. A kiln of this size and type will produce 150 barrels of cement a day.

The coal used in these kilns is bituminous nut and slack mixed, from Pittsburg or Jellico. About 25.6 pounds of coal are required to burn a barrel of cement (265 pounds), equivalent to a fuel consumption of about 9.5 per cent of the weight of cement produced.

Analyses of natural cements, Louisville district, Indiana and Kentucky.

	1	2	3	4	5	6	7	8
Silica (SiO_2)	18.92	21.10	22.54	23.29	24.40	25.28	26.40	23.13
Alumina (Al_2O_3)	11.02	7.50	8.24	5.96	6.20	7.85	6.28	7.87
Iron oxide (Fe_2O_3)	1.91		2.14	2.16		1.43	1.00	1.73
Lime (CaO)	46.90	44.40	42.31	41.28	41.80	44.65	45.22	43.79
Magnesia (MgO)	[a].97	7.00	5.39	15.39	16.29	9.50	9.00	10.43
Alkalies (Na_2O, K_2O)	n. d.	.80	2.82	1.98	1.52	n. d.	4.00	2.22
Carbon dioxide (CO_2)	n. d.	11.18	n. d.	n. d.	9.89	7.04	7.86	9.28
Water	n. d.	1.16	n. d.	n. d.				

[a] Probably erroneous.

1. Quoted by Jameson, Portland Cement, p. 177.
2. Quoted by Smith, Mineral Industry, vol. 1, p. 50.
3. Diamond brand. Haas and McGraw, analysts. Engineering News, April 30, 1896.
4. Star brand. Haas and McGraw, analysts. Ibid.
5. Lord, analyst. Rept. Ohio Geol. Survey, vol. 6, p. 674.
6. Hulme Star brand. Quoted by Cummings, American Cements, p. 35.
7. Fern Leaf brand. Quoted by Cummings. Ibid.
8. Average of preceding seven analyses.

NATURAL-CEMENT RESOURCES OF KANSAS.

The natural cement district of Kansas is located around Fort Scott, where a 4½-foot bed of natural cement rock outcrops. The rock is a dark-colored, fine-grained, compact limestone of Carboniferous age. It extends for a considerable distance throughout the State, but has been worked for natural cement only in the immediate vicinity of Fort Scott.

Analyses of natural-cement rock, Fort Scott, Kans.

	1	2	3	4
Silica (SiO_2)	15.21	17.26	21.80	18.09
Alumina (Al_2O_3)	4.56	2.05	3.70	3.44
Iron oxide (Fe_2O_3)	n. d.	5.45	3.10	4.27
Lime (CaO)	36.52	34.45	35.00	35.32
Magnesia (MgO)	5.07	5.28	3.50	4.62
Carbon dioxide (CO_2)	34.27	32.87	33.00	33.38

1. Smith, Mineral Industry, vol. 1, p. 49.
2. Brown, Cement Directory, 2d ed., p. 276.
3. Richardson, Brickbuilder, July, 1897.
4. Average of preceding three analyses.

Two types of kilns are in use in the Fort Scott district, Kansas. The more common type is cylindrical, 10 to 12 feet in diameter and 30 to 40 feet in total height. The lower 10 feet or so is of stone, on which is set the kiln proper. This is constructed of one-sixteenth inch sheet iron, lined with successive layers of coal ashes, clay, common brick, and fire brick. These kilns are drawn daily, and yield 60 to 75 barrels of cement each a day. The fuel used is slack coal, either Arkansas semibituminous from Poteau or Huntingdon or a very sulphurous local coal which underlies the cement rock at Fort Scott. The coal is fed with the rock, and is used at the rate of 30 to 35 pounds per barrel of cement, equal to a fuel consumption of 11.3 to 13.2 per cent of the weight of cement produced. At a three-flame kiln the burning is managed by five men—two feeding and three drawing the kilns.

At one of the Fort Scott plants four-flame kilns are also in use. These have separate fire places, so that the fuel and cement do not come into contact. Lump coal must be used for these kilns, and they are said to be more expensive, both in labor and fuel, than the type above described.

Analysis of natural cements, Fort Scott, Kans.[a]

Silica (SiO_2)	23.32
Alumina (Al_2O_3)	6.99
Iron oxide (Fe_2O_3)	5.97
Lime (CaO)	53.96
Magnesia (MgO)	7.76
Carbon dioxide (CO_2) Water	2.00

NATURAL-CEMENT RESOURCES OF MARYLAND AND WEST VIRGINIA.

The natural-cement industry of Maryland has been carried on in three separate areas. One of these areas includes the old plants at Antietam and Shepherdstown. The other two areas include respectively the plants at Cumberland and Potomac, in Allegany County, and that at Round Top, or Hancock, in Washington County. In both of these areas the limestones used are of the same geologic age and approximately of the same composition, so that they will be described together.

In geologic age the natural-cement rock of the Cumberland-Hancock district corresponds closely to that used in the various New York districts, being assigned by geologists to the Salina group of the Silurian. It is a shaly limestone, varying in color from dark bluish gray to dull black. In the Cumberland area it is exposed in four beds of sufficient thickness to be worked, these cement beds being separated by shales and limestones. The separate beds vary from 6 to 17 feet in thickness.

[a] Brockett's Double Star brand. Quoted by Cummings, American Cements, p. 35.

Analyses of natural-cement rocks, Cumberland and Hancock, Md.

	1	2	3	4	5
Silica (SiO_2)	19.81	24.74	27.10	28.72	22.07
Alumina (Al_2O_3)	7.35	16.74		12.28	12.12
Iron oxide (Fe_2O_3)	2.41	6.30	1.50	5.22	3.86
Lime (CaO)	35.76	23.41	36.40	25.54	30.28
Magnesia (MgO)	2.18	4.09	2.52	1.10	2.47
Alkalies (Na_2O, K_2O)	n. d.	6.18	.30	n. d.	([a])
Sulphur trioxide (SO_3)	n. d.	2.22	n. d.	1.53	([a])
Carbon dioxide (CO_2)	31.74	22.90	31.38	24.40	27.60
Water		n. d.	n. d.		

[a] Data insufficient for averaging.

1. Hancock, Md. C. Richardson, analyst. Brickbuilder, July, 1897.
2. Cumberland, Md. E. C. Boynton, analyst. Quoted by Gillmore, Limes, Cements, and Mortars, p. 125.
3. Hancock, Md. C. Huse, analyst. Quoted by Gillmore. Ibid.
4. Cumberland, Md. C. Richardson, analyst. Brickbuilder, July, 1897.
5. Average of preceding four analyses.

Analyses of natural cements, Cumberland and Hancock, Md.

	1	2	3	4	5	6	7	8
Silica (SiO_2)	25.70	28.02	28.30	28.36	28.38	30.02	36.60	29.34
Alumina (Al_2O_3)	12.28	10.20	10.12	9.85	11.71	13.55	14.58	11.76
Iron oxide (Fe_2O_3)	4.22	8.80	4.42	3.07	2.29	3.00	5.12	4.42
Lime (CaO)	52.69	44.48	49.60	45.04	43.97	44.58	37.50	45.41
Magnesia (MgO)	1.44	1.00	3.76	2.82	2.21	2.76	2.73	2.39

1. Cumberland, Md. A. W. Dow, analyst. Mineral Industry, vol. 6, p. 96.
2. Hancock, Md. Quoted by Cummings, American Cements, p. 36.
3. Cumberland, Md. A. W. Dow, analyst. Mineral Industry, vol. 6, p. 96.
4. Hancock, Md. A. W. Dow, analyst. Ibid.
5. Cumberland, Md. Quoted by Cummings, American Cements, p. 36.
6. Hancock, Md. A. W. Dow, analyst. Mineral Industry, vol. 6, p. 96.
7. Cumberland, Md. A. W. Dow, analyst. Ibid.
8. Average of preceding seven analyses.

NATURAL-CEMENT RESOURCES OF MINNESOTA.

Two natural-cement plants are in operation in Minnesota. One of them is located at Mankato, Blue Earth County, and uses a limestone of Lower Magnesian (Ordovician) age. The following analyses of the raw material used at this plant have been published:

Analyses of natural-cement rock from Mankato, Minn.

	1	2	3	4	5	6
Silica (SiO_2)	16.00	12.14	10.10	16.80	8.90	11.80
Alumina (Al_2O_3)	5.85	4.62	2.78	8.76	3.30	3.46
Iron oxide (Fe_2O_3)	2.73	1.84	1.34	Tr.	1.02	Tr.
Lime (CaO)	22.40	22.66	25.96	22.20	24.85	24.64
Magnesia (MgO)	14.99	16.84	14.91	11.99	18.49	16.61
Alkalies (K_2O, Na_2O)	.76	3.52	3.50	4.75	1.53	2.59
Sulphur trioxide (SO_3)	n. d.	.13	.26	.22	.18	.22
Carbon dioxide (CO_2)	34.11	39.07	41.29	35.90	41.80	40.85

1. C. F. Sidener, analyst. Eleventh Ann. Rept. Minn. Geol. Survey, p. 179.
2–6. Clifford Richardson, analyst. Cement Directory, p. 206.

The following analysis of the rock used by a natural-cement plant at Austin has also been published.

Analysis of natural cement rock from Austin, Minn.

Silica (SiO_2) } Alumina (Al_2O_3) }	15.59
Iron oxide (F_2O_3)	2.09
Lime (CaO)	27.55
Magnesia (MgO)	13.80
Sulphur trioxide (SO_3)	.06
Carbon dioxide (CO_2)	36.84

NATURAL-CEMENT RESOURCES OF NEW YORK.

In the State of New York natural cement is now manufactured in four distinct localities. These are, in order of importance, (1) the Rosendale district in Ulster County, (2) the Akron-Buffalo district in Erie County, (3) the Fayetteville-Manlius district, mostly in Onondaga County, and (4) Howes Cave, in Schoharie County.

The clayey limestones used in these four districts occur in three different but closely related geological formations, all in the Upper Silurian group. The sequence and relation of these formations, from the top downward, is shown in the following table:

Formation.	Ulster County.	Schoharie County.	Onondaga County.	Erie County.
Manlius limestone (cement rock).	....	....	Worked for cement at Manlius, etc.	Absent.
Rondout limestone (cement rock).	Upper cement bed of the Rosendale district.	Worked for cement at Howes Cave.	....	Absent.
Cobleskill limestone (not used for cement).	....	....	....	....
Bertie limestone (cement rock).	Lower cement bed of the Rosendale district.	....	Present in Onondaga County but rarely used for cement.	Worked for cement at Akron and Buffalo.

For convenience, these districts will be described not in the order of their relative importance, but in geographic order, from east to west.

ROSENDALE DISTRICT.

Rosendale district lies entirely in Ulster County, the principal cement-rock quarries being located at East Kingston, Rondout, Rosendale, Burnewater, Laurenceville, and High Falls. Two distinct beds

are worked at most of these points, differing in chemical composition as well as in geological age. Darton states[a] that at Rosendale the lower bed, or dark cement rock, averages about 21 feet in thickness, and the upper, or light cement rock, about 11 feet, the two cement beds being here separated by 14 or 15 feet of worthless limestone. The lower bed lies directly on the Clinton quartzite, the even upper surface of which affords an admirable floor for the galleries. For about 18 inches at the bottom the dark cement rock is too sandy for use. With this exception, and a few small layers of chert, it is all available. At Whiteport the upper bed is 12 feet thick and the lower 18 feet, while they are separated by 17 to 20 feet of limestone.

Analyses of natural-cement rock, Rosendale district, New York.

	1	2	3	4	5	6	7	8
Silica (SiO_2)	10.90	15.37	18.11	18.76	21.32	21.41	23.80	18.52
Alumina (Al_2O_3)	3.40	9.13	4.64	8.34	7.39	10.09	4.17	6.34
Iron oxide (Fe_2O_3)	2.28	2.25	3.00	1.85	1.71		4.71	2.63
Lime (CaO)	29.57	25.50	24.30	25.96	23.75	25.80	22.27	25.31
Magnesia (MgO)	14.04	12.35	14.26	11.00	11.07	10.09	12.09	12.13
Alkalies (K_2O, Na_2O)	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.
Sulphur trioxide (SO_3)	.61	n. d.	Trace.	1.35	1.90	.66	.90	.90
Carbon dioxide (CO_2)	37.90	34.20	34.01	32.00	30.74	30.93	31.00	33.31
Water	n. d.	1.20	n. d.	n. d.	n. d.		n. d.	

1. Lawrenceville. J. O. Hargrove, analyst. Letter to writer, October 4, 1900.
2. Rondout. L. C. Beck, analyst. Mineralogy of New York, p. 78.
3-5. Lawrenceville. J. O. Hargrove, analyst. Letter.
6. Rosendale district. C. Richardson, analyst. Brickbuilder, July, 1897.
7. Lawrenceville. J. O. Hargrove, analyst. Letter.
8. Average of preceding seven analyses.

In the Rosendale district cylindrical kilns are used. These vary from 8 to 12 feet in diameter and from 20 to 36 feet in height. A kiln fed with one-half ton of anthracite, pea size, will give 75 to 80 barrels of cement a day. This is equivalent to a fuel consumption of about 7 per cent on the weight of cement produced. From one-fifth to one-third of the total product of the kiln may be overburned clinker or underburned rock. This item, however, depends largely upon the skill of the burners, though it is also affected by uncontrollable factors, such as temperature, weather conditions, force and direction of the wind.

[a] Thirteenth Ann. Rept. N. Y. State Geologist, vol. 1, 1894, p. 334.

Analyses of natural cements, Rosendale district, New York.

Number.	Silica (SiO_2).	Alumina (Al_2O_3).	Iron oxide (Fe_2O_3).	Lime (CaO).	Magnesia (MgO).	Alkalies (K_2O, Na_2O).	Sulphur trioxide (SO_3).	Carbon dioxide (CO_2).	Water.
1	25.91	6.20	3.81	34.62	20.92	n. d.	n. d.	5.09	2.80
2	27.98	7.28	1.70	37.59	15.00	7.96	n. d.	2.49	
3	24.30	7.22	5.06	33.70	20.94	n. d.	n. d.	n. d.	n. d.
4	27.75	5.50	4.28	35.61	21.18	Tr.	0.50	4.05	n. d.
5	30.84	7.75	2.11	34.49	17.77	4.00	n. d.	3.04	
6	29.00	10.40		32.35	19.92	n. d.	n. d.	n. d.	n. d.
7	30.50	6.84	2.42	34.38	18.00	3.98	n. d.	3.78	
8	24.42	8.16	3.96	36.30	16.93	n. d.	n. d.	n. d.	n. d.
9	22.77	10.43		34.54	21.85	3.63	1.44	2.84	1.59
10	17.17	10.80		48.28	19.13	Tr.	1.20	3.38	n. d.
11	21.73	11.18	4.14	33.77	21.20	2.99	n. d.	n. d.	n. d.
12	27.30	7.14	1.80	35.98	18.00	6.80	n. d.	2.98	
13	29.98	6.88	2.50	33.23	17.80	7.10	n. d.	3.13	
14	22.75	13.40	3.30	37.60	16.65	n. d.	n. d.	5.00	1.36
15	28.87	7.96	3.19	35.89	18.95	......	......	......	......

1. "F. O. Norton." Private communication.
2. "F. O. Norton." Cummings, American Cements, p. 35.
3. "F. O. Norton." Lewis, Mineral Industry, vol. 6, p. 96.
4. Beach's. J. O. Hargrove, analyst: Private communication.
5. Brooklyn Bridge. Cummings, American Cements, p. 35.
6. Lawrenceville. A. W. Dow, analyst. Mineral Industry, vol. 6, p. 96.
7. Newark Lime and Cement Company. Cummings. American Cements, p. 35.
8. "Old Newark." Booth, Garrett & Blair, analysts. Mineral Industry, vol. 6, p. 96.
9. "Lawrence," Rosendale Cement Company. Mineral Resources United States for 1883-4.
10. "Hoffman," Lawrence Cement Company. Ibid. (very exceptional analysis).
11. "Hoffman," Lawrence Cement Company. Haas & McGraw, analysts, Engineering News, April 30, 1896.
12. "Hoffman," Lawrence Cement Company. Cummings, American Cements, p. 35.
13. "Rock Lock." Cummings. Ibid.
14. Rondout. L. C. Beck, analyst. Mineralogy of New York," p. 78.
15. Average of preceding fourteen analyses.

HOWES CAVE.

In the region north and northwest of the Rosendale-Rondout district no natural cement plants are to be found until Schoharie County is reached. Here, at Howes Cave, a single plant has long been engaged in the manufacture of cement from a 7-foot bed of rock.

Analyses of natural cement rock, Schoharie County, N. Y.

	1	2	3
Silica (SiO_2)	12.89	9.92	11.50 (Silica and alumina)
Alumina (Al_2O_3)	11.15 (Alumina and iron oxide)	n. d.	
Iron oxide (Fe_2O_3)		n. d.	1.50
Lime (CaO)	30.90	38.26	31.75
Magnesia (MgO)	9.38	9.00	14.91
Carbon dioxide (CO_2)	34.60	39.96	40.34

1. Bottom of cement bed, Howes Cave. C. O. Schaeffer, analyst. Eighteenth Ann. Rept. N. Y. State Geologist, p. 69.
2. Top of cement bed, Howes Cave. C. O. Schaeffer, analyst. Eighteenth Ann. Rept. N. Y. State Geologist, p. 69.
3. Howes Cave. L. C. Beck, analyst. "Mineralogy of New York," p. 79.

The following analysis is of the natural cement made at Howes Cave by the Helderberg Portland Cement Company:

Analysis of natural cement, Schoharie County, N. Y.

Silica (SiO_2)	26.54
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	5.89
Lime (CaO)	45.30
Magnesia (MgO)	17.06

CENTRAL NEW YORK.

The cement industry in central New York is at present practically confined to Onondaga County, though, as a matter of historical interest, it may be noted that the first natural cement made in the United States was manufactured in 1818 in Madison County.

The natural-cement rock of this central district occurs in two beds, which are usually separated by 1 to 4 feet of blue limestone. The upper cement bed is a little over 4 feet thick at the eastern border of Onondaga County, becoming thinner to the west until it pinches out entirely in the Split Rock quarries, but reappearing again at Marcellus Falls, where it is almost 3 feet thick, and showing a thickness of slightly over 4 feet at Skaneateles Falls. At this point it is separated from the lower cement bed only by a shaly parting a few inches thick, so that the two are worked together as practically one bed, 9½ feet thick. The lower bed is less variable in thickness, ranging from 4 to a trifle over 5 feet.

The entire cement series is overlain by purer limestones, but the cement rock quarries are usually located at points where these overlying limestones are thin and can be readily stripped.

Analyses of natural-cement rock, central New York.

	1	2	3	4	5	6
Silica (SiO_2)	10.97	10.95	13.50	8.95	11.76	10.66
Alumina (Al_2O_3)	4.46	5.32		4.90	2.73	4.35
Iron oxide (Fe_2O_3)	1.54	1.30	1.25	1.75	1.50	1.47
Lime (CaO)	27.51	30.92	25.24	27.35	25.00	27.20
Magnesia (MgO)	16.90	13.64	18.80	16.70	17.83	16.77
Carbon dioxide (CO_2)	37.94	38.31	39.80	38.65	39.33	38.81
Water	n. d.	n. d.	1.41	1.70	1.50	1.53

1. Upper cement bed, E. B. Alvord quarry, Jamesville, Onondaga County. Bull. 44, N. Y. State Mus., p. 806.
2. Lower cement bed, E. B. Alvord quarry, Jamesville, Onondaga County. Bull. 44, N. Y. State Mus., p. 806.
3. One and one-half miles west of Manlius, Onondaga County. L. C. Beck, analyst. "Mineralogy of New York," p. 81.
4. One and one-half miles southwest of Chittenango, Madison County. L. C. Beck, analyst. "Mineralogy of New York," p. 80.
5. Chittenango, Madison County. Seybert, analyst. Trans. Am. Philos. Soc., vol. 2, n. s., p. 229.
6. Average of preceding five analyses.

The kilns in the central New York district are described[a] as egg-shaped, 10 feet in diameter at the top, 12 feet at the middle, and 3½ feet at the bottom, with a height of 28 to 42 feet. There are usually several kilns built together in an embankment of very heavy masonry, so constructed against a hillside that the raw material can be conveniently conveyed there from the quarry and the burned cement easily removed from the bottom of the kiln. The kilns are built of limestone and lined either with sandstone or fire brick.

When a kiln is ready to be filled a cord of dry, hard, 4-foot wood is put into the bottom and covered 4 inches deep with coarse anthracite coal, then a layer 1 foot thick of cement rock, succeeded by another layer of coal, partly coarse and partly fine. This is repeated till the kiln is filled to the top, which required about 10 tons of coal and 15 cords of stone, equal to 1,500 bushels of cement. Then the fire is started at the bottom and gradually works its way upward until the whole mass is glowing with heat. After two or three days the gate or door in the bottom is opened and through it the burned cement rock is drawn to the amount of 250 to 300 bushels per day, fresh coal and rock being constantly added to keep the kiln full to the top. One cord of cement rock makes 100 bushels of cement.

Analyses of natural cements, central New York.

	1	2	3	4
Silica (SiO_2)	20.30	16.56	35.43	24.10
Alumina (Al_2O_3) Iron oxide (Fe_2O_3)	13.67	10.77	9.92	11.45
Lime (CaO)	47.48	39.50	33.67	40.22
Magnesia (MgO)	18.55	22.27	20.98	20.60

1. Brown Cement Co., Manlius, Onondaga County. W. M. Smith, analyst. Twentieth Ann. Rept. U. S. Geol. Survey, pt. 6, p. 428.
2. Near Chittenango, Madison County. L. C. Beck, analyst. "Mineralogy of New York," p. 80.
3. South of Utica, Oneida County. Gillmore, "Limes, Cements, and Mortars," p. 125.
4. Average of preceding three analyses.

AKRON-BUFFALO DISTRICT.

In Erie County natural-cement plants have long been established at Akron and Buffalo. The bed of cement rock used varies in thickness from 5 to 8 feet. It is a firm, fine-grained, compact rock of a blue-gray color, weathering to a yellowish white. The Buffalo plant works its cement rock by quarrying methods, stripping off the overlying limestones, but the plants at Akron all obtain their raw material by mining.

None of the analyses given below are entirely satisfactory. According to Mr. Uriah Cummings these analyses represent the composition of a bed of limestone occurring in the same quarries with the cement rock, but not actually used for cement.

[a] Luther, D. D. The economic geology of Onondaga County, N. Y. Fifteenth Ann. Rept. N. Y. State Geologist, vol. 1, pp. 241-303. 1897.

Analyses of natural-cement rocks, Akron-Buffalo district, New York.

	1	2	3	4
Silica (SiO_2)	9.03	10.68	[a] 33.80	9.85
Alumina (Al_2O_3)	2.25	4.61	3.96	3.10
Iron oxide (Fe_2O_3)	.85		.88	.87
Lime (CaO)	26.84	25.65	19.93	26.25
Magnesia (MgO)	18.37	17.93	9.17	18.15
Alkalies (K_2O, Na_2O)	.85	n. d.	n. d.	......
Sulphur trioxide (SO_3)	n. d.	n. d.	.50	......
Carbon dioxide (CO_2)	40.33	41.13	25.90	......
Water	.98			

[a] Called "Silica, clay, and insoluble silicates."

1. G. Steiger, analyst. Bulletin U. S. Geol. Survey, No. 168.
2. Lathbury and Spackman, analysts. Letter from manufacturers to writer, 1901.
3. E. Boynton, analyst. Gillmore, Limes, Cements, and Mortars, p. 125.

Mr. Heinrich Ries states that two types of kilns are in use at the Cummings plant at Akron, Erie County, N. Y. Of 17 kilns in use there at the time of his visit 8 were of rectangular cross section, 9 by 22 feet in area, with a height of 34 feet. The remaining 9 were circular in cross section, with a diameter of 9 feet and a height of 34 feet.

The crushing practice at the Cummings plant at Akron, N. Y., is stated[a] to include the following processes:

At this works a general system of reduction is used, consisting of (1) Sturtevant crushers, (2) Cummings pulverizers, (3) ten run of 42-inch underrunner millstones faced with chilled-iron plates, and (4) ten run of 42-inch Esopus underrunner millstones. The material, as it is conveyed from one to another of these sets of crushers, is made to pass over screens, whereby such material as has been reduced to proper fineness is separated from the mass and is spouted to a general conveyor, which finally receives the product from all the grinding machines and conveys it to the packing house.

Each set of crushers, while it furnishes a certain percentage of finished product, reduces the entire material to such fineness that what is fed to the fourth series is about the size of wheat kernels and very hard to reduce. These harder-burned portions make a cement which has a much higher tensile strength than the normally burned product.

The practice at the Buffalo plant, in Erie County, N. Y., is thus described by Ries:

Both the normally burned and the clinkered material are fed into the grinding machinery. The first set of machines are Stedman disintegrators, and the product from these is passed over a screen, all that passes through representing the normally

[a] Ries, H. Lime and Cement Industries of New York, Bulletin 44, New York State Museum, pp. 836–837.

burned cement rock. The clinkers which are not broken fine enough by the disintegrators to pass the screen are conveyed to a Griffin mill, where they are ground to make "Portland" cement.

Analyses of natural cements, Akron-Buffalo district, New York.

	1	2	3	4	5	6	7	8	9
Silica (SiO_2)	17.14	22.70	22.62	26.69	24.30	26.69	33.80	29.64	22.29
Alumina (Al_2O_3)	7.61	7.40	7.44	7.21	2.61	7.21	4.66	6.42	7.32
Iron oxide (Fe_2O_3)	2.00		1.40	1.30	6.20	1.30	......	......	1.57
Lime (CaO)	36.83	36.31	40.68	43.12	39.45	53.12	52.28	54.77	39.23
Magnesia (MgO)	25.09	25.72	22.00	19.55	6.16	9.55	9.26	9.17	23.12
Alkalies (K_2O, Na_2O)	3.64	n. d.	2.23	1.13	5.30	1.13	......	......	2.33
Carbon dioxide (CO_2)	n. d.	4.00	3.63	1.00	15.23	......	......	......	2.88
Water	n. d.								

1. "Union Akron" brand. Haas and McGraw, analysts. Engineering News, April 30, 1896.
2. "Buffalo Portland" brand. Lord, analyst. Report Ohio Geological Survey, vol. 6, p. 674.
3. "Newman Akron" brand. Quoted by Cummings. American Cements, p. 35.
4. "Obelisk" brand. Quoted by Cummings. Ibid.
5. "Buffalo Hydraulic" brand. Quoted by Cummings. Ibid.
6–8. Quoted by Uriah Cummings in letter to writer, January 30, 1901, as analyses of various cements made at Akron. Compare No. 6 with No. 4.
9. Average of analyses Nos. 1, 2, 3, and 4.

NATURAL-CEMENT RESOURCES OF NORTH DAKOTA.

The single natural-cement plant operating in this State is located about 10 miles east of Milton, Cavalier County. The rock used is a soft, chalky limestone of Cretaceous age, and outcrops in a bluff several hundred feet high. At present, however, only a 10-foot bed is being worked by mining.

Analyses of natural cement, North Dakota.

	1	2	3	4	5	6	7	8	9
Silica (SiO_2)	24.62	23.60	23.90	24.72	24.40	24.40	24.06	24.46	......
Alumina (Al_2O_3), Iron oxide (Fe_2O_3)	15.12	16.50	15.90	15.00	15.26	15.38	15.00	15.30	......
Lime (CaO)	52.30	51.40	51.40	51.30	52.07	51.96	51.96	52.37	......

1–8. Analyses of natural cement, Pembina Cement Company, Milton, N. Dak.
9. Average of preceding eight analyses.

At the Pembria plant a kiln 40 feet high and 10 feet in external diameter is used. The shell is of one-eighth-inch No. 14 boiler iron. The kiln space is broadest at the top, narrows down to a throat about 6 feet in diameter, below which it again enlarges, reaching almost to the kiln shell at 15 feet above the base. Below this it is again some-

what contracted to the drawing level. The kiln space is lined with 8-inch fire brick, and the space between these brick and the kiln shell is filled with ashes. This kiln produces about 50 barrels of 265 pounds each a day, with a fuel consumption of 1 ton of Youghiogheny slack. Lignite slack, mixed half and half with Youghiogheny slack, has been used at times, and apparently gives almost as good results as the bituminous slack alone. About 10 per cent of the total product is underburned or clinkered. This record is about equivalent to a fuel consumption of 40 pounds per barrel, or 15.1 per cent on the weight of cement produced. This is rather high fuel consumption for natural cement; but, on the other hand, the product is of peculiarly high grade, passing most Portland standards.

Analysis of natural cement rock, North Dakota.

	1	2	3	4	5	6	7	8	9	10
Silica (SiO_2)	14.00	16.60	13.10	16.20	16.54	14.90	15.24	19.20	17.36	16.00
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	6.70	7.10	7.60	7.56	8.20	8.28	7.26	8.90	8.78	7.50
Lime (CaO)	37.60	35.50	37.80	35.10	35.20	36.90	36.70	32.60	34.90	35.60
Sulphur trioxide (SO_3)	.58	.60	n. d.	n. d.	n. d.	n. d.	.40	n. d.	n. d.	.67
Sulphur (S)	1.45	1.38	n. d.	n. d.	n. d.	n. d.	1.99	n. d.	n. d.	1.61

NATURAL-CEMENT RESOURCES OF OHIO.

Small natural-cement plants have been established at various points in Ohio, those at Defiance and New Lisbon being worthy of some notice. The Defiance plant used a black calcareous shale of Devonian age. If published analyses be correct (see Nos. 1 and 2 in the following table), this rock is by far the most argillaceous material used anywhere for this purpose.

Analyses of natural-cement rocks, Ohio.

	1	2	3	4	5
Silica (SiO_2)	39.95	42.00	16.41	30.60	15.65
Alumina (Al_2O_3)	20.22	7.00	5.44	13.00	6.80
Iron oxide (Fe_2O_3)		7.10	3.38		2.50
Lime (CaO)	10.06	9.91	26.05	22.74	38.64
Magnesia (MgO)	2.92	5.81	12.55	7.23	1.62
Carbon dioxide (CO_2)	24.03	14.18	34.32	25.81	32.14
Water and organic		14.00	n. d.	n. d.	n. d.

1. Defiance. J. E. Whitfield, analyst. Bull. U. S. Geol. Survey No. 55, p. 80.
2. Defiance. R. C. Kedzie, analyst. Cement Directory.
3. Bellaire. N. W. Lord, analyst. Repts. Ohio Geol. Survey, vol. 6, p. 673.
4. Warnock. Wormley, analyst. Rept. Ohio Geol. Survey, 1870, p. 451.
5. New Lisbon. N. W. Lord, analyst. Rept. Ohio Geol. Survey, vol. 6, p. 673.

NATURAL-CEMENT RESOURCES OF PENNSYLVANIA.

A fairly large production of natural cement has always been maintained in the Lehigh district of eastern Pennsylvania, though at present natural-cement manufacture there is merely incidental to the great Portland cement industry of the district.

The analyses following purport to be representative of the rock used at various Lehigh district natural cement plants. It is hardly necessary to say that Nos. 1 and 3 are absolutely unfit for such use. No. 2, on the other hand, is quite satisfactory. It is regrettable that these very untrustworthy analyses are at present the only ones available.

Analyses of natural-cement rock, Lehigh district, Pennsylvania.

	1	2	3	4
Silica (SiO_2)	11.62	18.34	27.77	19.24
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	6.25	7.49	14.29	9.34
Lime (CaO)	44.20	37.60	29.94	37.25
Magnesia (MgO)	1.27	1.38	1.55	1.40
Carbon dioxide (CO_2)	36.11	31.06	26.30 (with water)	32.47 (with water)
Water	n. d.	3.94		

1. Siegfried, Pa. Mineral Industry, vol. 1, p. 49.
2. Coplay, Pa. Ibid.
3. Lehigh district. Quoted by C. Richardson. Brickbuilder, July, 1897.
4. Average of preceding three analyses.

The natural-cement kilns at one of the prominent Lehigh district plants are about 30 feet in height, and of circular cross-section. Internally they are almost exactly cylindrical, being 10 feet in diameter at the top and 9½ feet in diameter at the base. The cement rock and fuel are fed in alternate layers, the fuel being anthracite coal broken to about one-half inch size. From 35 to 50 pounds of coal are required to burn one barrel (300 pounds) of cement, corresponding to a full consumption of 11.6 per cent to 16.7 per cent of the weight of cement produced.

Analyses of natural cements, Lehigh district, Pennsylvania.[a]

	1	2
Silica (SiO_2)	18.18	18.28
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	9.78	7.43
Lime (CaO)	69.18	51.53
Magnesia (MgO)	1.98	2.07
Alkalies (K_2O, Na_2O)	n. d.	1.50
Sulphur trioxide (SO_3)	n. d.	n. d.
Carbon dioxide (CO_2)	n. d.	16.26 (with water)
Water	n. d.	

[a] Quoted by Smith. Mineral Industry, vol. 1, p. 50.

NATURAL-CEMENT RESOURCES OF TEXAS.

The analysis below has been published[a] as representing the average of the material used in making natural cement by a Texas natural-cement plant. It is obvious that, if this statement be correct, the product obtained by burning a rock of such composition can not be a natural cement in any proper use of the term. It would, in fact, be merely a very weak hydraulic lime.

Analysis of natural cement rock, Texas.

Silica (SiO_2)	5.77
Alumina (Al_2O_3)	2.14
Iron oxide (Fe_2O_3)	
Lime (CaO)	50.45
Magnesia (MgO)	.28

NATURAL-CEMENT RESOURCES OF VIRGINIA.

For many years natural cement has been burned near Balcony Falls, Rockbridge County, Va. The rock used is a clayey magnesian limestone of Cambrian age, closely related geologically to that used in West Virginia, and described below.

Analyses of natural-cement rock, Virginia.

	1	2	3
Silica (SiO_2)	17.38	17.21	17.30
Alumina (Al_2O_3)	7.80	Tr.	6.18
Iron oxide (Fe_2O_3)		1.62	1.62
Lime (CaO)	34.23	24.85	29.54
Magnesia (MgO)	9.51	16.58	13.05
Carbon dioxide (CO_2)	30.40	37.95	34.17

1. Balcony Falls. E. C. Boynton, analyst. Gillmore, "Limes, Cements, and Mortars," p. 125.
2. Balcony Falls. C. L. Allen, analyst. "The Virginias," vol. 3, p. 88.
3. Average of preceding two analyses.

NATURAL-CEMENT RESOURCES OF WEST VIRGINIA AND MARYLAND.

A wide belt of magnesian limestones of Cambrian age crosses Maryland into the eastern part of West Virginia. Several small natural-cement plants have been established at various times in this district, particularly near Antietam, Md., and Shepherdstown, W. Va.

NATURAL-CEMENT RESOURCES OF WISCONSIN.

Two plants in Wisconsin are engaged in the manufacture of natural cement from a clayey magnesian limestone of Devonian age. These

[a] Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 3, p. 787.

plants are located north of Milwaukee, near the lake. The cement rock deposit is very thick compared to most deposits of similar rock, a quarry face 22 feet high being worked by the Milwaukee Cement Company.

Analyses of natural-cement rocks, Milwaukee district, Wisconsin.

	1	2	3	4
Silica (SiO_2)	17.00	17.56	17.56	16.99
Alumina (Al_2O_3)	4.25	1.41	1.40	5.00
Iron oxide (Fe_2O_3)	1.25	3.03	2.24	1.79
Lime (CaO)	24.64	25.50	27.14	23.15
Magnesia (MgO)	11.90	15.45	13.89	16.60
Carbon dioxide (CO_2)	32.46	37.05	36.45	36.47

1. Mineral Industry, vol. 6, p. 95.
2-4. Trans. Am. Inst. Min. Eng., vol. 8, p. 507.

The Campbell kilns in use at the plant of the Milwaukee Cement Company hold a charge equivalent to about 400 barrels (265 pounds each) of cement. This is drawn at the rate of 125 to 130 barrels a day, all the drawing for the day being done in ten hours. Nut and slack coal, mixed, are used for fuel. The fuel consumption amounts to about 30 pounds per barrel of cement, equivalent to 11.3 per cent of the weight of the cement produced.

Analyses of natural cements, Milwaukee district, Wisconsin. [a]

Silica (SiO_2)	23.16
Alumina (Al_2O_3)	6.33
Iron oxide (Fe_2O_3)	1.71
Lime (CaO)	36.08
Magnesia (MgO)	20.38
Alkalies (K_2O, Na_2O)	5.27
Sulphur trioxide (SO_3)	n. d.
Carbon dioxide (CO_2) / Water	7.07

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[a] Quoted by Cummings. American Cements, p. 35.

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PART IV. MATERIALS AND MANUFACTURE OF PUZZOLAN CEMENTS.

PUZZOLANIC MATERIALS.

Puzzolanic materials include all those natural or artificial substances that are capable of forming hydraulic cements on being simply mixed with lime, without the use of heat. Many materials possess this property, but relatively few have ever attained sufficient commercial importance to be discussed here. In composition the puzzolanic materials are largely made up of silica and alumina, usually with more or less iron oxide; some, as the slags used in cement manufacture, carry also notable percentages of lime. As might be inferred from this composition, most of the puzzolanic materials possess hydraulicity to a greater or less degree, but the addition of lime usually greatly increases their hydraulic power.

NATURAL PUZZOLANIC MATERIALS.

Natural puzzolanic materials are widely distributed, though they have never attained much commercial importance save in Europe. They may be divided into two classes, according to origin. In the first class may be included all those which are the direct products of volcanic action, the material being a fine volcanic ash or dust deposited either on the slopes of the volcano or carried by the wind to lakes or streams in which the ash is deposited. This group includes the more active puzzolanic materials, its chief representatives being pozzuolana proper, santorin, tosca, tetin, and trass. It may be noted that in origin materials of this class resemble closely the granulated slags used in slag-cement manufacture, both volcanic ashes and granulated slags being due to the two processes of (1) fusion of a silico-aluminous material, and (2) rapid cooling of the resulting product by ejection into air or immersion in water. The second class includes a number of less important (because less active) hydraulic materials, such as arénes, psammites, etc., which are materials resulting from the decay of certain igneous rocks.

Pozzuolana derives its names from the little town of Pozzuoli, located a few miles west of Naples, at which point the material was first

obtained by the Greek colonists, and at a later date by the Romans. The material has also been exploited at other points near Rome and Naples.

Most of the Italian pozzuolana is obtained from small open cuts or pits, though some of these workings are now of great depth. Those of Trentaremi, for example, are about 600 feet deep. The various deposits differ greatly in the quality of the materials obtained from them. Care should therefore be exercised in selecting a spot for exploitation, and sorting of the material dug would be advisable in order to keep the product of uniformly high grade. After extraction the material is screened and ground. In addition it is occasionally slightly roasted to increase its hydraulic properties. Carelessness, both in the mining and in the later preparation of the pozzuolana, has brought the Italian article somewhat into disrepute among European engineers. In consequence it is losing ground with respect both to pozzuolana from the Azores and to trass from Rhenish Prussia.

Pozzuolana has been shipped from San Miguel, in the Azores, to Portugal for over a hundred years, and has been used with very satisfactory results in many important buildings, harbor works, etc. The Azores pozzuolana varies in color from yellowish to brownish, and sometimes to greyish. It is frequently so fine grained as not to require screening or grinding before use. A reddish-colored variety from the same islands is termed tetin.

The following analyses of pozzuolana are fairly typical of its range in composition:

Analyses of pozzuolana, Italy.

	1	2	3	4
Silica (SiO_2)	52.66	60.91	56.31	44.5
Alumina (Al_2O_3)	14.33	21.28	15.23	15.0
Iron oxide (Fe_2O_3)	10.33	4.76	7.11	12.0
Lime (CaO)	7.66	1.90	1.74	8.8
Magnesia (MgO)	3.86	.00	1.36	4.7
Alkalies (K_2O, Na_2O)	4.13	10.60	11.38	5.4
Water, etc	7.03	n. d.	6.12	9.2

Trass, another puzzolanic material of commercial importance, is found in the districts bordering the Rhine in Rhenish Prussia. The towns of Brohl, Kruft, Plaidt, and Andernach, all about 10 to 15 miles southwest of Coblenz, are the principal points near which the material is worked. Trass is an ancient volcanic mud composed of a groundmass of volcanic dust, in which fragments of pumice, volcanic rocks, etc., are embedded.

In composition trass varies between the following extremes: Silica, 45 to 65 per cent; alumina, 10 to 23 per cent; iron oxide, 3 to 12 per cent; lime, 1 to 8 per cent; magnesia, 0 to 3 per cent; alkalies, 1 to 7 per cent; water, carbon dioxide, etc., 3 to 12 per cent.

Santorin, another puzzolanic material, is obtained from the island of Santorin, or Thera, one of the most southeasterly of the islands of the Grecian Archipelago.

ARTIFICIAL PUZZOLANIC MATERIALS.

By far the most important of the puzzolanic materials is blast-furnace slag, especially in the United States, where natural puzzolanic materials of domestic origin have never come into use, though trass and puzzolanic cements made from it are imported to a small extent. Slag, on the other hand, is the basis of an important industry—the manufacture of slag (puzzolan) cement. The materials and processes used in making this product will be described in some detail on the following pages.

THE MANUFACTURE OF SLAG CEMENT.

Slag (puzzolan) cement is made by intimately mixing granulated blast-furnace slag of proper composition with slaked lime, and reducing this mixture to a fine powder. This product, though usually called a Portland cement by the manufacturers, is different from a true Portland in both its rational and ultimate compositions and in its processes of manufacture. Further than this and more important from the purchasers' standpoint, a cement of this class has certain qualities which prevent its being used as an exact substitute for Portland cement, though it is a good enough material for certain uses.

COMPOSITION OF THE SLAG.

The slag used in cement manufacture must be basic blast-furnace slag. Tetmajer, the first investigator of slag cements, announced as the results of his experiments (*a*) that the hydraulic properties of the slag increased with the proportion of lime contained in it, and that slags in which the ratio $\frac{CaO}{SiO_2}$ was so low as to approach unity were valueless for cement manufacture; (*b*) that, so far as the alumina content of the slag was concerned, the best results were obtained when the ratio $\frac{Al_2O_3}{SiO_2}$ gave a value of 0.45 to 0.50; and (*c*) that with any large increase of alumina above the amount indicated by this value of the alumina-silica ratio the tendency of the cement to crack (when used in air) was increased.

Prost, at a later date, investigated the subject, using for experiment several commercial slags and also a series prepared from pure CaO, SiO_2, and Al_2O_3. He decided that the hydraulic properties (both as regards rapidity of set and ultimate strength) of the slag increased as the proportions of lime and alumina increased, and failed to find any indication that a high alumina content causes disintegration. His best results were obtained from slags having the compositions respectively of $2SiO_2$, Al_2O_3, $3CaO$ and $2SiO_2$, Al_2O_3, $4CaO$.

Mahon in 1893 made a series of experiments to determine the value (for cement manufacture) of a large series of the slags produced by the furnaces of the Maryland Steel Company, and found that the slags giving the best results were two, having respectively the following compositions:

(1) SiO_2, 30 per cent; Al_2O_3, 17 per cent; CaO, 47.5 per cent; S, 2.38 per cent; and (2) SiO_2, 25.3 per cent; Al_2O_3, 20.1 per cent; CaO, 48 per cent; MgO, 3.28 per cent; S, 2.63 per cent.

The ratios of $\frac{CaO}{SiO_2}$ and $\frac{Al_2O_3}{SiO_2}$, calculated for these slags are—

$$(1)\ \frac{CaO}{SiO_2}=1.58;\ \frac{Al_2O_3}{SiO_2}=0.57;\ \text{and}\ (2)\ \frac{CaO}{SiO_2}=1.9;\ \frac{Al_2O_3}{SiO_2}=0.79.$$

At the close of the experiments Mahon recommended that slags be used even slightly higher in alumina than those above quoted.

The specifications under which slag from the furnaces is accepted by the cement department of the Illinois Steel Company are as follows:

(1) Slag must analyze within the following limits:

$SiO_2+Al_2O_3$ not over 49 per cent; Al_2O_3, from 13 to 16 per cent; MgO, under 4 per cent.

(2) Slag must be made in a hot furnace and must be of a light-gray color.

(3) Slag must be thoroughly disintegrated by the action of a large stream of cold water directed against it with considerable force. This contact should be made as near the furnace as is possible.

A series of over 300 analyses of slags used by this company in their slag (puzzolanic) cement, show the following range in composition:

SiO_2, 29.60 to 35.60 per cent; Al_2O_3 and Fe_2O_3, 12.80 to 16.80 per cent; CaO, 47.99 to 50.48 per cent; MgO, 2.09 to 2.81 per cent.

The requirements of the Birmingham Cement Company as to the chemical composition of the slags used for cement are as follows: The lime content shall not be less than 47.9 per cent; the silica and lime together shall approximately amount to 81 per cent; and the alumina and iron oxide together shall equal from 12 to 15 per cent.

Analyses of a number of slags used in cement manufacture are shown in the table below. The analyses of foreign slags are quoted from various reliable authorities and the five analyses of the Illinois

Steel Company slags have been selected from a large series to show the extreme ranges of the different elements. The ratios $\frac{CaO}{SiO_2}$ and $\frac{Al_2O_3}{SiO_2}$ have been calculated for each slag and are shown in this table.

From these data it can be seen that the ratio of alumina to silica is carried very high at Choindez; and is rather low at Chicago, relatively to most of the European plants. It must be remembered, however, that one reason for carrying a high alumina-silica ratio does not apply at Chicago, as there rapidity of set is gained by the use of the Whiting process. Taking these two plants as representative of the best European and American practice, the average of the analyses given shows the ratios actually used to be: Choindez, Switzerland, $\frac{CaO}{SiO_2}=1.71$, $\frac{Al_2O_3}{SiO_2}=0.90$; and Chicago, Ill., $\frac{CaO}{SiO_2}=1.49$, $\frac{Al_2O_3}{SiO_2}=0.44$.

These results may be compared with the theoretical ratios advised by Tetmajer, Prost, and Mahon.

Analyses of slags used in slag cements.

	Silica (SiO_2).	Alumina (Al_2O_3).	Iron oxides (FeO, Fe_2O_3).	Lime (CaO).	Magnesia (MgO).	Lime sulphide (CaS).	Lime sulphate ($CaSO_4$).	Sulphur (S).	Sulphur trioxide (SO_3).	Ratio, $\frac{CaO}{SiO_2}$.	Ratio, $\frac{Al_2O_3}{SiO_2}$
1	30.00	28.00	0.75	32.75	5.25	1.90	....	....	....	1.09	0.93
2	31.50	18.56	....	42.22	3.18	....	....	0.45	2.21	1.34	.59
3	32.90	13.25	.46	47.30	1.37	3.42	....	....	....	1.44	.41
4	31.50	16.62	.62	46.10	....	....	....	....	....	1.46	.52
5	26.88	24.12	.44	45.11	1.09	1.86	....	....	....	1.68	.89
6	27.33	23.81	.63	45.83	.92	1.34	0.17	....	....	1.67	.87
7	26.24	24.74	.49	46.83	.88	.59	.32	....	....	1.78	.93
8	32.20	15.50	....	48.14	2.27	....	....	....	....	1.49	.48
9	33.10	12.60	....	49.98	2.45	....	....	....	....	1.51	.38
10	31.80	14.80	....	49.74	2.29	....	....	....	....	1.56	.46
11	34.30	14.76	....	48.11	2.66	....	....	....	....	1.40	.43

1, 2. Middlesborough, England.
3. Bilbao, Spain.
4. Saulnes, France.
5, 6, 7. Choindez, Switzerland.
8, 9, 10, 11. Chicago, Ill.

The erection of a slag-cement plant in connection with any given furnace is not justified unless a sufficient amount of the slags usually produced will fall within the slag-cement requirements, which have been outlined above in the section on chemical composition of the slag (?). In a large plant it will usually be easy to secure a constant supply of slag of proper composition without interfering with the proper running of the furnaces. In a small plant, however, or in one running on a number of different ores, such a supply may be difficult

to obtain. These points, of course, should be settled in advance of the erection of the cement plant.

In the case of any given furnace running on ores and fluxes which are fairly steady in composition and proportions, the selection of the slag used for cement making may often be largely based on its color, checked by determinations of lime. The darker-colored slags are generally richest in lime, except when the depth of color is due to the presence of iron; the lighter-colored slags are usually higher in silica and alumina. Candlot states further[a] in this connection that the slag issuing at the commencement and toward the end of a discharge should be rejected because of the chilling which attends its slow movement.

GRANULATING THE SLAG.

Assuming that a slag of proper composition has been selected, the first step in the actual manufacture of slag cement will be the "granulation" of the molten slag. Granulation is produced by bringing molten slag into contact with a sufficient amount of cold water. The physical effect of this proceeding is to cause the slag to break up into porous particles (slag "sand"). Granulation has also certain chemical effects, highly important from an economic point of view, which will be discussed later (p. 363).

Methods of granulating the slag.—The success of the granulation depends on bringing the slag into contact with the water as soon as possible after it has left the furnace. The effects of the process will be found to vary with (*a*) the temperature of the slag at the point of contact, (*b*) the temperature of the water, (*c*) the amount of water used, and (*d*) its method of application.

Taking up the last point first, it may be noted that two general methods of application of the water have been used. In one the stream of slag as it issued from the furnaces is struck by a jet of steam under pressure. This method, which was used at one time in the Middleboro district, England, blows the slag into fine threads, with attached globules. It is, in fact, much the same as the process still used in the manufacture of mineral wool, which is elsewhere discussed. From an economic point of view it has the advantage of putting the slag in a condition in which it is easily pulverized by the grinding machinery; but it has certain inconveniences, and has been almost or entirely superseded by the method now to be mentioned.

The second way in which the water may be applied is to allow the stream of slag as it issues from the furnace to fall into a trough containing a rapidly flowing stream of cold water. Care must be taken that the fall into the trough is not too great, and that the stream of water is deep enough and fast enough, for otherwise the slag will

[a] Ciments et chaux hydrauliques.

acquire sufficient momentum in its fall to solidify in a mass on the bottom of the trough. This method is in use at all slag-cement plants of the present day, being occasionally modified by the use, in addition to the flowing stream of water in the trough, of a jet of water playing on the slag before it strikes the trough.

Effects of granulating the slag.—The physical effect of causing hot slag to come in contact with cold water is to break the slag up into small, porous particles. As this materially aids in pulverizing the slag, it is probable that granulation would be practiced on this account alone. But as a matter of fact granulation has, in addition to its purely physical result, two important chemical effects. One is to make the slag, if it be of suitable chemical composition, energetically hydraulic; the other is to remove a portion of the sulphides (contained in the slag) in the form of hydrogen disulphide.

Le Chatelier states that the hydraulic properties of granulated slag are due to the presence of a silico-alumino ferrite of calcium corresponding in composition to the formula $3CaO, Al_2O_3, 2SiO_2$. This compound appears also in Portland cements, but in them it is entirely inert, owing to the slow cooling it has undergone. When, however, as in the case of granulated slags, it is cooled with great suddenness, it becomes an important hydraulic agent. When so cooled "it is attackable by weak acids and also by alkalies. It combines particularly with hydrated lime in setting, and gives rise to silicates and aluminates of lime identical with those which are formed, by entirely different reactions, during the setting of Portland cement. It is upon this property that the manufacture of slag cements, which assumes daily greater importance, is based."

DRYING THE SLAG.

The slag as it is brought to the cement mill from the granulating tanks carries from 15 to over 40 per cent of water absorbed during granulation. As will be noted later (p. 366) attempts have been made to utilize this contained water in the slaking of the lime, but these attempts have hitherto proved unsuccessful. As the manufacture is at present conducted, therefore, the large percentage of water carried by the slag is of no service, and in order to get good results from the grinding machinery the water must be removed as completely as possible before pulverization is attempted.

Before the various types of dryers in use are described, a few words may be said on the general problem. The slag may carry, as above noted, from 15 to over 40 per cent of water, the percentage varying with the method of granulation, the fineness of grain, etc. As the slag must be reduced to extreme fineness, it is necessary that this moisture be reduced as much as possible. With a well-conducted rotary drier it

is possible to economically reduce the percentage of moisture in the dried product to about one-fourth of 1 per cent.

The temperature to which the product is carried in drying is not a matter of serious moment so long as it does not pass the point at which the slag begins to recrystallize. Theoretically, of course it is unnecessary to carry the temperature above 212° F., but in practice it is economically impossible to keep it as low as this. It may be carried as high as a dull-red heat without injury to the slag. Indeed, it is probable that drying at relatively high temperatures improves rather than impairs the hydraulic properties of the slag, as it is well known that the natural pozzuolanas are improved by roasting. It would not, therefore, be a matter of surprise if drying the slag at a higher temperature than is actually necessary should result in materially accelerating the set of the resulting cement, and also in increasing the strength of briquettes made from it.

The Ruggles-Coles dryer consists of two concentric hollow cylinders bolted together and revolving on an axis slightly inclined from the horizontal. The outer cylinder is made of steel plates, the longitudinal seams having butt joints with inside lapping straps. The inner cylinder, which is also made of steel, is connected with the outer cylinder at the center by heavy cast-iron arms solidly riveted to both cylinders, and at each end by two sets of adjustable or swinging arms, which prevent expansion and contraction from affecting the rivets or joints. At the head or upper end the inner cylinder projects beyond the outer cylinder, passing into a stationary head or air chamber to the hot-air flue of the furnace with which it is connected. At the lower or discharge end is another stationary head, forming an air chamber, through an opening in the bottom of which the dried material is discharged. This head is provided with a damper to regulate the temperature.

The outer cylinder is set at an inclination of about 0.375 inch to the foot. It is secured to two heavy rolled-steel bearing rings which rest and revolve upon eight bearing wheels supported by oscillating arms or rockers. The lateral motion of the cylinder is taken up by four thrust wheels. The dryer is revolved by a cast gear secured to the outer cylinder, and this is driven by a shaft and pinion extended beyond the end of the machine and supported in two babbitted journal boxes fitted to the frame. The entire machine is fitted and secured to a heavy frame of 8-inch I beams braced and framed together and usually set on a concrete foundation. The exhaust fan is placed where most convenient to drive and is connected with the outer cylinder by suitable flue. The furnace is built independent of the machine and connected with the head end of the inner cylinder by an iron flue built with fire brick. A specially designed burner is substituted for the furnace for the use of oil, gas, or powdered coal.

The heated air passes through the inner cylinder and returns between the inner and outer cylinders to the fan. The slag is fed into the space between the inner and outer cylinders through a spout in the stationary head at the upper end of the machine. It is picked up by buckets or carriers fastened to the inner surface of the outer cylinder and carried partly around during the rotation of the dryer. On dropping from these buckets it falls and is caught on the flights fastened to the outer surface of the inner cylinder, which carry it partly around and then drop it to the bottom of the outer cylinder, when the cycle commences again. While these movements of the slag are occurring it is being dried both by the heated air in the space between the two cylinders and by contact with the warm outer surface of the inner cylinder, and it is also being carried slowly toward the lower (discharge) end of the machine.

The following table shows working results in the use of the Ruggles-Coles dryer on granulated slag:

Results of use of Ruggles-Coles dryer.

User.	Original moisture.	Final moisture.	Water evaporated per hour.	Dry material delivered per hour.	Coal used per hour.	Water evaporated per pound of coal.
	Per cent.	*Per cent.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
Knickerbocker Cement Co	41.82	0.20	4,401	6,399	560	7.87
Maryland Cement Co	20.32	.25	4,114	16,173	542	7.59
Birmingham Cement Co	45.00	....	4,181	4,987	537	7.60
Southern Cement Co	40.00	....	4,707	7,061	550	8.56

COMPOSITION AND SELECTION OF THE LIME.

The lime used for admixture with the slag may be either a quicklime (common lime) or a hydraulic lime. In usual American practice, and also at most European plants, a quicklime is used. At a few American, French, and German plants, however, limes which have more or less hydraulic properties are employed. Prost has carried on experiments touching this point and decided that the use of a hydraulic lime did not noticeably increase the tensile strength of the resulting cement, but that it did increase the value of the product in another way. This incidental advantage is that slag cements made by using hydraulic lime are less liable to fissure and disintegrate when used in air or in dry situations than cement in which common quicklime is used. This method of improving the product has been tried, to the writer's knowledge, at only one of the American slag cement plants. At Königshof, Germany, a somewhat hydraulic lime is used, whose analysis will be fairly representative of materials of this type, though most hydraulic limes would run higher in silica and alumina.

Analysis of hydraulic lime, Königshof, Germany.

Lime (CaO)	81.546
Magnesia (MgO)	1.751
Soda (Na_2O)	.211
Silica (SiO_2)	12.421
Alumina (Al_2O_3)	2.620
Iron oxide (Fe_2O_3)	.883
Manganese oxide (MnO_2)	Trace.
Carbon dioxide (CO_2)	.194
Moisture (H_2O)	.425

DRYING AND SLAKING THE LIME.

The granulated slag, as it comes to the mill from the tanks to which it is carried in granulating it, holds a very large percentage of water. The amount of water carried will vary in practice at different plants between 25 and 50 per cent as limits. Early in the history of slag-cement manufacture attempts were made to utilize this surplus water. To this end the wet slag was mixed with dry unslaked lime, the expectation being that the water in the slag would serve to slake the lime. In practice, however, it was soon found that this plan was not successful. The lime was only partially and very irregularly slaked, and the mixture was not left in such a condition as to be economically handled by the pulverizing machinery. In present-day practice, therefore, the lime is slaked before it is mixed with the slag.

The slaking is done with the minimum possible amount of water, so as to leave the slaked lime in the form of a fine, dry powder.

SIEVING AND GRINDING THE LIME.

If lime has been thoroughly burned and carefully slaked it will all be in the form of a very fine powder, much finer than can be obtained by any economically practicable grinding machinery. In practice, however, it will be found that the lime after slaking has not all fallen to powder but still contains a certain proportion of hard lumps. The degree of carefulness with which the burning and slaking have been conducted may be roughly judged by observing the relative proportions of lumps and powder.

The material remaining as lumps is of three different kinds. First and in greatest proportion, are fragments of limestone which have not been thoroughly burned in the kiln. Such unburned pieces would be inert if used in the cement. Second, part of the lumps represent fragments of limestone which have been overburned in the kiln, and have therefore partly clinkered. This is particularly likely to happen if the limestone contained any large proportion of silica or alumina. These partly clinkered lumps, being really poor-grade natural cements, can, if pulverized, do no particular harm to the slag

cement, but, on the other hand, they can not do as much good as an equal amount of lime. The third kind of material that may be present in lump form consists of fragments of well-burned lime which, through accident or carelessness, have not been well slaked. These lumps of quicklime would, if incorporated in the cement, be actively injurious.

The preceding description and discussion of the three classes of material which are likely to remain as lumps in the slaked lime has been intentionally made detailed, in order to point out an error in practice committed occasionally at slag-cement plants. It has been seen that the materials composing these lumps are of such a character as to be either useless or actively injurious if used in a slag cement. It should be obvious, therefore, that the only rational method of treatment is to sieve the slaked lime and to reject entirely all the material failing to pass through the sieve. This is the best practice and the method usually followed. Occasionally, however, urged by a false idea of economy or by inaccurate reasoning, the manufacturer saves the material failing to pass the sieve, crushes it, and adds it to the cement at a later stage in the manufacture.

MIXING AND GRINDING THE SLAG AND LIME.

Prost, in consequence of his experiments with various proportions of lime, advocated the proportion, to secure the best results, of from 35 to 40 parts of lime to 100 parts of slag. He also stated that the amounts of lime used in actual practice for each 100 pounds of slag were: At Choindez, 40 to 45 pounds; at Donjeux, 40 pounds; at Brunswick, 33 pounds, and at Cleveland, 33 pounds. Mahon, in reporting his experiments for the Maryland Steel Company, states that the best results were secured by the use of 25 parts of lime to 100 parts of slag, by weight. In the manufacture of slag brick, which is in reality merely a branch of the slag-cement industry, the amount of lime added may fall as low as 10 pounds to 100 pounds of slag.

In actual American practice the proportions are usually about 20 pounds lime to 100 pounds slag. This difference in proportions between the American and European plants corresponds to a difference in the composition of the slags used, for in this country the slags employed in slag-cement manufacture are usually somewhat higher in lime than are the slags used at European plants.

The greatest differences in practice exist in the processes for grinding and mixing the slag and lime. The statement has been made in several publications that the differences in hardness between dry granulated slag and slaked lime is so great that it is impracticable to pulverize them together in a continuously operated mill. A number of plants, therefore, have installed small discontinuous mills, each of

which is charged, locked, operated for a sufficient time to pulverize both constituents of the mixture, and discharged. The disadvantages of this intermittent system are obvious and it seems especially unfitted for American conditions. The statement that no continuously operated mill was able to handle the mixture seemed improbable in view of the great variety of material successfully handled by the modern ball and tube mills when operated continuously in Portland-cement practice. Several years ago the writer referred the question to a leading firm of manufacturers, and was informed that nothing in their experience justified the unfavorable conclusion; and that their continuously operated tube mills had successfully pulverized mixtures of slag and lime. It seems probable that the most economical practice, followed at several of the American plants, would be to send the dried slag through a Griffin mill or ball mill, mix the crushed slag with lime, and complete the mixture and reduction in continuously operated tube mills. Whatever system of reduction is employed it is necessary that the slag be dried as completely as possible, and with modern driers the amount of moisture in the dried slag can be economically kept well below 1 per cent.

Slag cements normally set very slowly, relative to Portlands. As this interferes with their use for certain purposes, many attempts have been made, by various treatments, to reduce their setting time. There is, unfortunately, another reason why the manufacturer should desire to hasten the set of his product. Most of the slag cements sold in this country masquerade as Portland, and it is desirable to the manufacturer therefore to make such of their properties as are brought out in ordinary tests or analyses approximate to those of true Portland cement. The set of slag cements can be hastened by the addition of puzzolanic materials. Of these burned clay, certain active forms of silica, and slags high in alumina are the cheapest and most generally obtainable. The most important method of regulation is, in this country at least, the Whiting process, which is followed at two large American plants.

United States Patent No. 544706, issued in 1895 to Jasper Whiting, covers the use of "caustic soda, potash, sodium chloride or equivalents, or any substance of which the latter are ingredients," added either as aqueous solutions or in a dry state at any stage of the process of slag-cement manufacture. In the specifications accompanying the application for this patent, the patentee states that in the case of dry caustic soda the amount added will vary from 0.125 to 3 per cent, "depending chiefly upon the use for which the cement is intended." The patent was subsequently conveyed to the Illinois Steel Company, and the process covered by it is used by that company in the manufacture of its "Steel Portland" cement. A license has been issued to the

Brier Hill Iron and Coal Company, of Youngstown, Ohio, under which license this company manufactures its "Brier Hill Portland" cement.

The process, as practiced in the slag-cement plant of the Illinois Steel Company, Chicago, Ill., is as follows: The quicklime used is obtained from the calcination of Marblehead or Bedford limestone, and carries less than 1 per cent MgO. On its arrival at the mill it is unloaded into bins, beneath which are placed two screens of different mesh, the coarser at the top. A quantity of lime is drawn upon the upper screen, where it is slaked by means of the addition of water containing a small percentage of caustic soda. As the lime is slaked it falls through the coarse screen onto the finer screen, through which it falls into a conveyor which carries it to a rotary drier. After heating, the resulting slaked and dried lime is carried by elevators to hoppers above the tube mills, where it is mixed in proper proportions with the granulated slag, which has been dried and powdered.

COMPOSITION AND PROPERTIES OF SLAG CEMENT.

Slag cement when ready for sale is a mechanical mixture of lime hydrate($Ca_2(OH)_2$) and a calcium-aluminum silicate($x SiO_2, Al_2O_3, y CaO$). In addition to the essential ingredients noted above, certain others of less amount usually occur. The most important of these in the effect it produces on the quality of the product is sulphur, which is obtained from the slag in the form of sulphides of lime or iron. To the presence of these sulphides is due, in large part at least, the disintegration of slag cements when used in dry air. If the cement be used for construction in water, their presence is of much less importance, and the total sulphides may run as high as 5 per cent without seriously impairing the quality. Several per cent of iron oxide obtained from the slag are commonly present. Magnesia also occurs, derived from the slag or the lime. It is inert, if not positively detrimental, and the amount therefore should be kept as low as possible.

In addition to the ingredients mentioned above, a percentage, usually small, of other compounds may be found, which have been added by the manufacturer during some stage of the process for the purpose of increasing the rapidity of set of the cement.

The table below contains the analysis of a number of American and European slag cements, as given by various authorities. It will be seen that, despite the apparently great variations in practice, the ultimate composition of the finished cement falls within quite narrow limits. The range in composition of a good slag cement may be considered to be about: SiO_2, 22 to 30 per cent; $Al_2O_3+Fe_2O_3$, 11 to 16 per cent; CaO, 49 to 52 per cent; MgO, less than 4 per cent; S, less than 1.5 per cent; ignition loss, 2.5 to 7.5 per cent.

Analyses of slag cements.

	1	2	3	4	5	6	7	8	9	10
Silica (SiO_2)	19.5	30.56	22.45	27.20	28.40	28.95	29.80	27.80	27.0	27.78
Alumina (Al_2O_3)	17.5	13.31	13.95	14.18	12.80	11.40	12.30	11.10	12.0	11.70
Iron oxides (FeO, Fe_2O_3)	n.d.	0.25	3.30			0.54				
Lime (CaO)	54.0	45.01	51.10	50.03	51.50	50.29	51.14	50.96	55.0	51.71
Magnesia (MgO)	n.d.	2.96	1.35	3.22	n.d.	2.96	2.34	2.23	n.d.	1.39
Sulphur (S)	n.d.	[a]4.63	.....	.....	1.40	1.37	1.37	1.18	n.d.	1.31
Sulphur trioxide (SO_3)	n.d.	[b]1.41	0.35	0.15	.....	.....	.....	.....	.....	.....
Loss on ignition	n.d.	n.d.	7.50	4.25	n.d.	3.39	2.60	5.30	n.d.	n.d.

[a] Equals CaS. [b] Equals $CaSO_4$.

1. Choindez, Switzerland.
2. Bilbao, Spain.
3. Saulnes, France.
4, 5, 6, 7, 8, Chicago, Ill.
9. North Birmingham, Ala.
10. Ensley, Ala.

IDENTIFICATION OF SLAG CEMENT.

Slag cements may usually be distinguished from Portland cements by their lighter color, inferior specific gravity, and slower set. They show on analysis lower lime and higher alumina percentages than Portlands, and usually contain an appreciable amount of calcium sulphide. Owing to the presence of this last-named constituent, a briquette of slag cement left for some days in water will show upon fracture a decided greenish tint. If it has been exposed to salt water, this tint will be much more marked and the odor of hydrogen sulphide will be observed. Two things should be noted, however, in this connection: Though sulphides are usually present in slag cements they are not necessary constituents of them, and, on the other hand, sulphides are occasionally present in Portland cements, being formed from the sulphates in case the flame of the kiln is not sufficiently oxidizing.

Color.—Slag cements are usually much lighter in color than the Portlands, varying from a bluish white to a light yellow. The color of the cement depends partly upon the color of the slag and the lime, but more largely upon the relative proportions of the two ingredients. Slag cements do not stain masonry, in which respect they have an advantage over Portlands for certain uses.

Specific gravity.—Cements of this class are lighter than Portlands, their specific gravity usually ranging from 2.7 to 2.8. This gives a greater bulk for the weight, but, on the other hand, it reduces the density of the set cement, which is not desirable for some purposes.

Rapidity of set.—Normally slag cements are slower setting than Portlands. Whether this property is a disadvantage or not will

depend on the use to which the cement is to be applied. As before mentioned, the rapidity of set increases naturally with the amount of alumina in the slag. Set can be artificially hastened by the addition of puzzolanic material to the cement. Burned clay, certain active forms of silica, slags high in alumina, etc., are additions which are both effective and cheap. The treatment of the cement during manufacture with alkalies to accelerate the set has already been discussed.

Strength.—While slag cements fall below high-grade Portlands in tensile strength, good American slag cements develop sufficient strength to pass the usual specifications for Portlands. Tested neat, they do not approximate so closely to the Portlands as they do if tested in 2:1 or 3:1 mortars. Part of this property may be due to the fact that they are, in general, ground finer than Portlands, especially than foreign Portlands. A few years ago Prof. W. K. Hatt made a series of tests on American slag cements, and reported that there was no noticeable deficiency in strength of briquettes kept in air as compared with those kept in water. Other investigators have arrived at opposite conclusions, and it is probable that these conflicting results arise from differences in the chemical composition of the various brands tested.

Resistance to mechanical wear.—Slag cements are notably deficient in this property, and are therefore not available for use for the surfaces of pavement, floors, etc., where this quality must be highly developed; they seem to be well fitted, however, for pavement foundations, or indeed for any work which will not be exposed to dry air and in which a high strength is not necessary.

PLANTS, PRICES, AND USES.

Of the seven slag-cement factories now in operation in the United States, two each are located in Alabama and Ohio, and one each in Illinois, New Jersey, and Pennsylvania. Most of the plants now in operation are connected closely in ownership with the furnaces from which the slag is obtained. This condition is almost a necessity, since common ownership or control furnishes the only possible guaranty that a sufficient supply of slag, of proper quality, will be always available.

The selling price of slag cements is highly variable, as can be understood from statements made on previous pages. Whenever possible, they are sold as Portlands, and in that case approximate in price to cements of that class. When necessary, however, they are marketed at prices below those of natural cements. Taking the entire annual product into consideration, its price per barrel will probably average about 20 to 25 per cent higher than the best brands of natural cements

(New York Rosendale). The industry affords very fair profits, and the output in the United States is increasing steadily.

American slag cements are certainly superior in strength, uniformity, and rapidity of set to European slag cements. Slag cements are not, however, Portland cements, and the sooner this fact is recognized and publicly admitted by their manufacturers the better will be the prospects of the industry. For, though slag cements are entirely unfitted for many uses to which Portland cements may be applied, there are certain uses for which they are well adapted, and if, for any particular use, a slag cement is as good as a Portland, its lower price will of necessity remove any danger of Portland competition.

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J. C. Branner

Bulletin No. 244 Series C, Systematic Geology and Paleontology, 69

DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

CONTRIBUTIONS TO DEVONIAN PALEONTOLOGY

1903

BY

HENRY SHALER WILLIAMS

AND

EDWARD M. KINDLE

WASHINGTON

GOVERNMENT PRINTING OFFICE

1905

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ILLUSTRATIONS.

LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., May 31, 1904.

SIR: I have the honor to transmit herewith the manuscript of a report entitled "Contributions to Devonian Paleontology, 1903," by Henry Shaler Williams and Edward M. Kindle, and to recommend its publication as a bulletin. The report consists of two parts: I. Fossil faunas of the Devonian and Mississippian ("Lower Carboniferous") of Virginia, West Virginia, and Kentucky. II. Fossil faunas of the Devonian sections of central and northern Pennsylvania.

Very respectfully,

C. W. HAYES,
Geologist in Charge of Geology.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

CONTRIBUTIONS TO DEVONIAN PALEONTOLOGY, 1903.

PART I.

FOSSIL FAUNAS OF THE DEVONIAN AND MISSISSIPPIAN ("LOWER CARBONIFEROUS") OF VIRGINIA, WEST VIRGINIA, AND KENTUCKY.

BY

HENRY SHALER WILLIAMS and EDWARD M. KINDLE.

CONTENTS OF PART I.

CONTRIBUTIONS TO DEVONIAN PALEONTOLOGY, 1903.

PART I.—FOSSIL FAUNAS OF THE DEVONIAN AND MISSISSIPPIAN ("LOWER CARBONIFEROUS") OF VIRGINIA, WEST VIRGINIA, AND KENTUCKY.

By H. S. WILLIAMS and E. M. KINDLE.

INTRODUCTION.

By H. S. WILLIAMS.

The investigations herein reported were begun for the purpose of ascertaining the nature of the changes in sedimentation, in fossils, and in sequence of faunas southward along the Devonian formations in the southern Appalachians. Collections were made by the senior author in southern Virginia and eastern Kentucky in 1895, and the results of the preliminary study of the fossils were reported in a paper read before the Geological Society of America in December, 1896.[a]

In southern Virginia (at Bigstone Gap) the Devonian is represented by a continuous black shale, which probably runs upward beyond the stratigraphic horizon at which Carboniferous faunas appear in other regions. In east-central Kentucky the black shale, supposed to be in large part Devonian, continues upward beyond the horizon at which the earliest Carboniferous faunas appear. In neither the Bigstone Gap nor the Irvine (Ky.) sections was any trace of the Chemung fauna of New York seen. At several places, at the base of the black shales, the latest fauna appears to be no younger than Oriskany, and suggested that either there was an unconformity at the base or a black shale sedimentation continued during post-Oriskany Devonian time. Evidence of the unconformity at the base of the black shale is furnished by the sections at Brooks station, 15 miles south of Louisville, and at Huber, Bullitt County, Ky.

In order to demonstrate the conditions intermediate between those represented by the typical northern sections and by the sections in the southern Appalachians, Dr. E. M. Kindle in 1898 made a special

[a] On the southern Devonian formations: Am. Jour. Sci., 4th ser., vol. 3, 1897, pp. 395-405.

examination of the Devonian sections in Kentucky, West Virginia, and Virginia. Additional collections were thus obtained, and later all the material was studied together and the faunules listed and compared. The original identifications in the following paper were made by Doctor Kindle. They have been reviewed by the senior author, who is responsible for the discussions which follow the statistics.

KENTUCKY SECTIONS.

By E. M. KINDLE.

The Kentucky sections examined furnished faunules from the following localilies:

Sections examined in Kentucky.

1355 A. Bear Grass Creek quarries near Louisville, Ky.
1357 A. Jeffersonville, Clark County, Ind.
B. Jeffersonville, Indiana side, near Government jetty.
C. South end of Pittsburg, Cincinnati, Chicago and St. Louis Railway bridge, Louisville, Ky.
1365 A. Brooks, Bullitt County, Ky.
B. Button Mold Knob, three-fourths of a mile northeast of Brooks.
C. One mile west of Brooks station.
1367 A. Railroad cut, one-fourth of a mile south of Huber, Bullitt County, Ky.
1368 A. Quarry at Clermont, Bullitt County, Ky.
B. Ravine about one-fourth of a mile southeast of quarry, Clermont, Ky.
C. Section at Deerlick Knob, Bullitt County.
1371 A. West of town of New Haven, Nelson County, Ky., on bank of Rolling Fork.
B. About 5 miles south of New Haven along the pike at Muldrows Hill.
1372 A. Northwest of Riley station, Marion County, Ky.
B. South of Riley station.
1373 A. About three-fourths of a mile west of Parksville, Boyle County, Ky.
B. An old quarry in the "Knobstone" sandstone, 1½ miles west of Parksville.
1374 A. Lone Knob, near Junction City, Boyle County, Ky.
1375 A. Crab Orchard, Lincoln County, Ky.

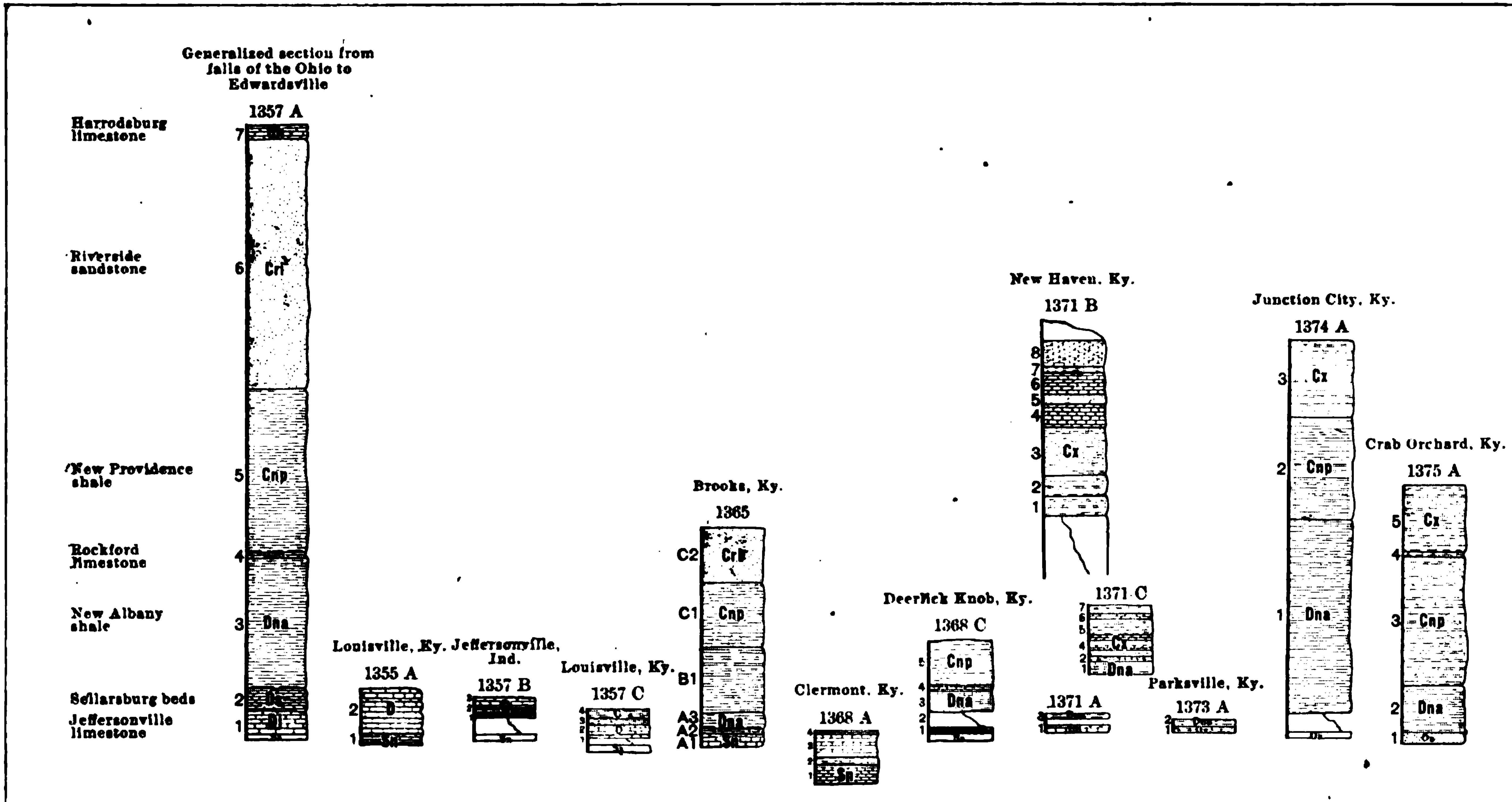
BEAR GRASS CREEK QUARRIES, NEAR LOUISVILLE, KY.

Just east of Louisville the Niagara limestone is extensively quarried along the banks of Bear Grass Creek. The tops of the hills in the vicinity of the quarries are usually capped with from 10 to 15 feet of Devonian limestone. The following section is exposed at the quarry south of the institution for the blind:

Section 1355 A, on Bear Grass Creek, Kentucky.

	Feet.
2. White to light gray limestone (Devonian)	10
1. Light bluish-gray arenaceous limestone (Niagara)	35

In the Niagara beds (1) corals are common, but other fossils are scarce and difficult to obtain. The following species were collected from the lower part of the section:



SECTIONS IN INDIANA AND KENTUCKY NEAR LOUISVILLE.

Faunule of zone 1 of section 1355 A, on Bear Grass Creek, Kentucky.

[c, common; r, rare.]

1. Strombodes striatus (c).
2. S. sp. (c).
3. Cladopora sp. (r).
4. Halysites catenulatus (c).
5. Lyellia papillata (c).
6. Heliolites sp. (c).
7. Stromatopora sp. (r).
8. Cornulites proprius (r).
9. Dalmanella elegantula (r).
10. Conchidium nysius (r).
11. Uncinulus cf. stricklandi (r).
12. Atrypa reticularis (r).
13. A. reticularis var. niagarensis (r).
14. Dalmanites vigilans (r).

In the upper 10 feet of the section fossils are abundant. *Spirifer gregarius* Clapp occurs in great profusion, and, with a few species of corals, furnishes the greater part of the faunule in some of the strata. The fossils identified from these beds are as follows:

Faunule of zone 2 of section 1355 A, on Bear Grass Creek, Kentucky.

[a, abundant; c, common; r, rare.]

1. Zaphrentis sp. (c).
2. Pleurodictyum problematicum (r).
3. Crinoid stems (c).
4. Polypora sp. (r).
5. Stropheodonta demissa (c).
6. S. hemispherica (r).
7. S. (Leptostrophia) perplana (r).
8. Orthothetes chemungensis var. arctostriatus (r).
9. Chonetes mucronatus (r).
10. Schizophoria striatula (c).
11. Pentamerella arata (r).
12. Eunella lincklæni (r).
13. Atrypa reticularis (a).
14. Spirifer acuminatus (r).
15. S. byrnesi (r).
16. S. gregarius (a).
17. S. varicosus (r).
18. Conocardium trigonale (r).
19. Aviculopecten princeps (r).
20. Platyceras carinatum (r).
21. P. dumosum (r).
22. P. echinatum (r).
23. Proetus crassimarginatus (c).
24. Phacops cristata var. pipa (r).

OHIO FALLS AND EDWARDSVILLE SECTIONS.

The Niagara limestones, which are so well exposed just east of Louisville, are brought below the bed of the Ohio at the falls by the westerly dip, which is probably about 25 or 30 feet to the mile. A connected section from the Falls of the Ohio to Edwardsville, on the Indiana side of the river, shows the following beds:

Generalized section 1357 A, from Falls of the Ohio to Edwardsville.

	Feet.
7. Gray limestone (Harrodsburg)	60
6. Massive to shaly sandstone and sandy shales (Riverside), with 1 to 10 feet of oolitic limestone in upper part	200
5. Blue arenaceous shales (New Providence)	125
4. Fine-grained limestone (Rockford), breaking with conchoidal fracture	3
3. Fissile black carbonaceous shale (New Albany)	104
2. Argillaceous blue-gray limestone (Sellarsburg beds)	15
1. Light-gray limestone (Jeffersonville)	20

Fossils were obtained from the Jeffersonville limestone at the exposure on the north bank of the river, about half a mile below the Pittsburg, Cincinnati, Chicago and St. Louis Railway bridge (1357 A1).

The Jeffersonville limestone is exposed at low-water mark, near the Government jetty on the Indiana side of the river. Fossils were obtained from each of the the three zones of this limestone given below:

Section 1357 B, Jeffersonville limestone on north side of Ohio River.

	Feet.
3. Light-gray limestone	6
2. Hard gray limestone	2
1. Exposed at low water	3

Near the south end of the Pittsburg, Cincinnati, Chicago and St. Louis Railway bridge, in Louisville, Ky., the fine-grained calcareous sandstones lying below the black shale are quarried for cement. Three or 4 feet of rather pure limestone separate these sandy beds from the black shale at the upper end of the canal. The section is composed of the following zones:

Section 1357 C, at Louisville, Ky.

	Ft.	in.
4. Black shale (at upper end of canal)	1	
3. Light-gray limestone	3	6
2. Cement beds (Sellarsburg)	8	
1. Jeffersonville limestone (not exposed).		

The faunules collected from the rocks at the Ohio Falls and in the vicinity are as follows:

Faunule of zone 1 of section 1357 A, at Jeffersonville, Clark County, Ind.

[a, abundant; c, common; r, rare.]

1. Zaphrentis gigantea (c).
2. Z. ungula (c).
3. Blothrophyllum decorticatum (c).
4. Diphyphyllum sp.
5. Thecia minor (c).
6. Favosites hemisphericus (c).
7. Michelinia cylindrica (c).
8. Discina sp. (r).
9. Stropheodonta demissa (c).
10. S. hemispherica (c).
11. S. (Leptostrophia) perplana (r).
12. Chonetes sp. (r).
13. Productella spinulicosta (r).
14. Orthis cf. livia (r).
15. Schizophoria striatula (r).
16. Gypidula romingeri var. indianensis (r).
17. Atrypa aspera (r).
18. A. reticularis (a).
19. Cyrtina hamiltonensis (r).
20. Spirifer arctisegmentus (r).
21. S. euruteines (r).
22. S. byrnesi (r).
23. S. gregarius (a).
24. Conocardium trigonale (r).
25. Trochonema rectilatera (r).
26. Platyceras dumosum (r).
27. Platyostoma lineatum (r).
28. Proetus canaliculatus (r).

Faunule of zone 1 (Jeffersonville limestone) of section 1357 B, on north side of Ohio River.

[a, abundant; c, common; r, rare.]

1. Zaphrentis gigantea (a).
2. Blothrophyllum sp. (c).
3. Favosites hemisphericus (c).
4. Syringopora sp. (c).
5. Stropheodonta demissa (c).
6. S. (Leptostrophia) perplana (r).
7. Pentamerella arata (r).
8. Eunella lincklæni (c).
9. Spirifer gregarius (r).
10. S. varicosus (r).
11. Conocardium cuneus (a).
12. Modiomorpha mytiloides (r).
13. Pleurotomaria sp. (r).
14. Holopea sp. (r).
15. Proetus crassimarginatus (c).
16. P. microgemma (r).

Faunule of zone 2 of section 1357 B, on north side of Ohio River.

[a, abundant; c, common; r, rare.]

1. Zaphrentis gigantea (c).
2. Cyathophyllum rugosum (c).
3. Stropheodonta demissa (c).
4. S. (Leptostrophia) perplana (r).
5. Orthothetes chemungensis (r).
6. Chonetes mucronatus (c).
7. Schizophoria cf. striatula (r).
8. Atrypa reticularis (c).
9. Cyrtina hamiltonensis (r).
10. Spirifer gregarius (a).
11. Glyptodesma occidentale (r).
12. Conocardium cuneus (a).
13. Actinopteria boydi (r).
14. Ptychodesma sp. nov. (r).
15. Modiomorpha affinis (a).
16. M. mytiloides (a).
17. Turbo shumardi (c).
18. Callonema bellatulum (c).
19. C. cf. imitator (c).
20. Proetus crassimarginatus (c).
21. Dalmanites anchiops var. sobrinus (r).
22. D. selenurus (r).

Faunule of zone 3 of section 1357 B, on north side of Ohio River.

[c, common.]

1. Stropheodonta demissa (c).
2. S. hemispherica (r).
3. Chonetes mucronatus (c).
4. Atrypa reticularis (c).
5. Spirifer acuminatus (c).
6. Proetus cf. crassimarginatus (c).

Faunule of zone 2 (Sellarsburg cement beds) of section 1357 C, at Louisville, Ky.

[a, abundant; c, common; r, rare.]

1. Stropheodonta demissa (r).
2. Chonetes yandellanus (a).
3. Leiorhynchus quadricostatum (c).
4. Atrypa reticularis (a).
5. Spirifer oweni (a).
6. S. segmentus (c).
7. S. subattenuatus (r).
8. Proetus sp. (r).

The only fossil found in the black shale (New Albany) at Louisville (1357 A3) was *Lingula spatulata*.

Near the mouth of Silver Creek, below the falls, *Schizobolus concentricus* occurs abundantly in the black shale (1357 A3).

The Rockford limestone (1357 A4) contains no fossils at its exposures near New Albany. This limestone appears to be absent south of the Ohio.

BROOKS, BULLITT COUNTY, KY.

A connected section of the rocks in the vicinity of Brooks station, about 15 miles south of Louisville, is made up of beds exposed at the three following localities: (A) Brooks, Bullitt County; (B) Button Mold Knob, three-fourths mile northeast of Brooks; (C) 1 mile west of Brooks. The general section is as follows:

Generalized section 1365, near Brooks, Ky.

	Feet.
C2. Massive sandstone	40 to 50
C1. Sandy shale and sandstone	50 to 75
B1. Blue clay shale	50 to 65
A3. Black shale (New Albany)	15 to 30
A2. Limestone (Devonian)	2 to 6
A1. Limestone and sandstone (Niagara)	15 to 20
	172 to 246

The black shale (A3) rests unconformably on the Devonian limestone in the vicinity of Brooks. In the bed of Brooks Run, between the railroad and the wagon road, the lowest strata of the black shale lie in shallow, irregularly eroded pockets in the limestone. In some of these a thin layer of reddish clay was observed between the limestone and the undisturbed black shale. The unconformity is illustrated in the accompanying figure.

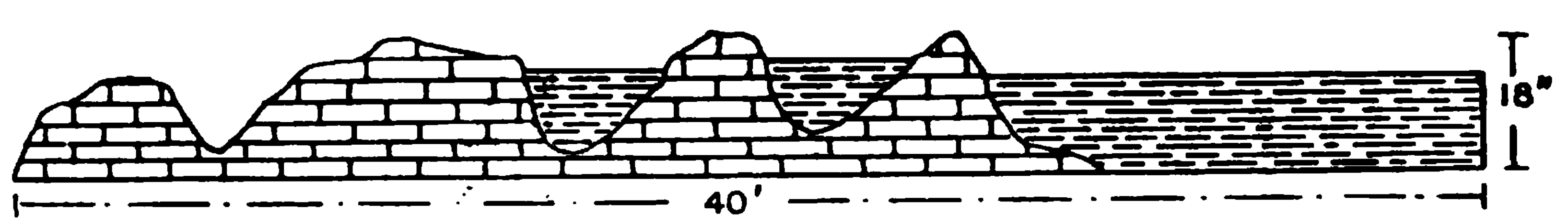


FIG. 1.—Section on Brooks Run, Bullitt County, Ky., showing unconformity between (black) New Albany shales and the Devonian (Jeffersonville) limestone.

One-half mile northeast of Brooks the shale (New Albany) has a drab color, and furnished the following faunule:

Faunule of zone 3 of general section 1365 A, near Brooks, Ky.

[c, common.]

1. Lingula spatulata (c).
2. Chonetes scitulus (c).
3. Leiorhynchus cf. quadricostatum (c).
4. Pleurotomaria sp. (c).

The upper argillaceous member of the Devonian (Sellarsburg beds), which is worked for cement at Louisville, is entirely wanting in this section. The Devonian limestone in the section represented by fig. 1 probably does not exceed 2 feet in thickness. Below it is the siliceous Niagara limestone (A1), which outcrops in the wagon road and contains the following species:

Faunule of zone 1 of general section 1365 A, near Brooks, Ky.

[c, common.]

1. Favosites niagarensis (c).
2. Halysites catenulatus (c).

The Devonian limestone in the bed of Brooks Run, between the railroad and wagon road, Brooks, Ky., afforded the following fossils:

Faunule of zone 2 of general section 1365 A, near Brooks, Ky.

[c, common; r, rare.]

1. Stropheodonta demissa (r).
2. S. (Leptostrophia) perplana (c).
3. Rhipidomella livia (r).
4. Pentamerella arata (r).
5. Camarotœchia sp.
6. Atrypa reticularis (c).
7. Spirifer fornacula (r).
8. S. varicosus (r).
9. Actinopteria sp.
10. Proetus crassimarginatus (c).
11. Phacops rana (r).

The blue clay shale (New Providence) at the base of Button Mold Knob contains the following species:

Faunule of zone 1 of general section 1365 B, near Brooks, Ky.

[a, abundant; r, rare.]

1. Zaphrentis sp. (r).
2. Amplexus sp. (r).
3. Crinoid stems (a).
4. Orthothetes crenistria (r).
5. Chonetes illinoisensis (r).
6. Rhipidomella oweni (a).
7. Spirifer suborbicularis (a).
8. Platyceras sp. (a).

The latest fauna of the section is obtained from the massive sandstone (Riverside) 1 mile west of Brooks station, Ky.

Faunule of zone 2 of general section 1365 C, near Brooks, Ky.

[c, common; r, rare.]

1. Fenestella sp. (c).
2. Discina sp. (r).
3. Orthothetes crenistria (r).
4. Derbya keokuk (c).
5. Productus burlingtonensis (c).
6. Camarotœchia sappho (c).
7. Syringothyris carteri (c).
8. Cypricardinia sp. (r).

HUBER, BULLITT COUNTY, KY.

The unconformity between the black shale and the underlying limestones is well shown in the section exposed in the railroad cut one-fourth mile south of Huber.

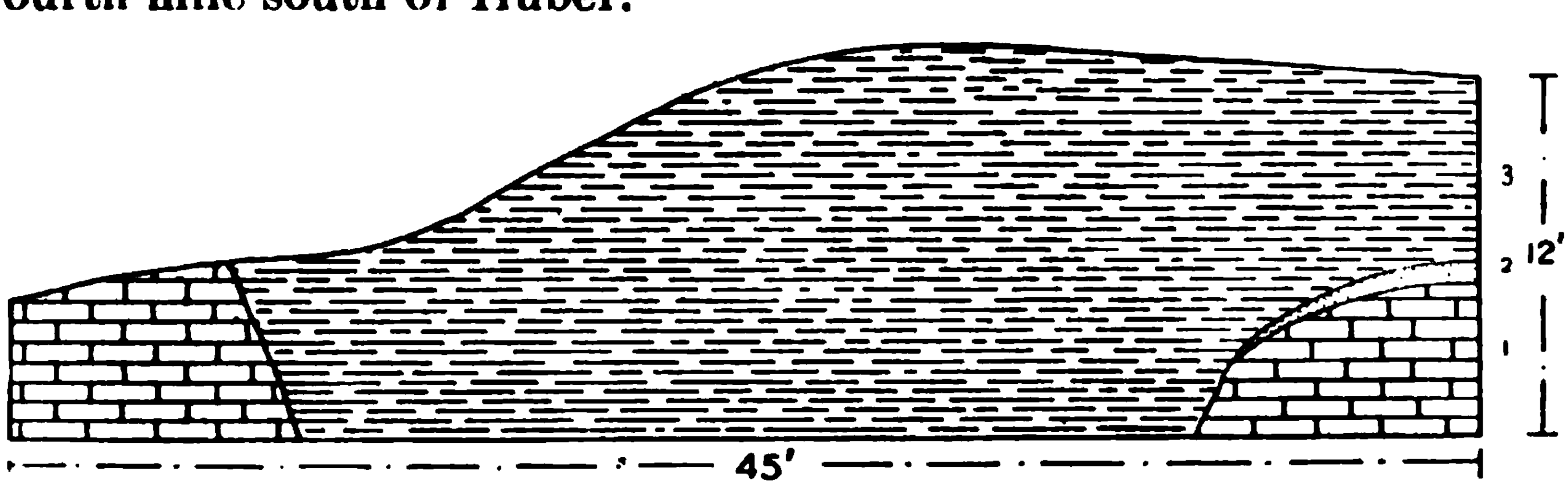


FIG. 2.—Section 1367 A, showing unconformity of the black shale and the Devonian limestone south of Huber, Ky. 1, Devonian limestone; 2, red clay; 3, black shale.

As shown in fig. 2, the shale on one side of the section is separated from the limestone by about 4 inches of red clay.

The limestone (Sellarsburg) directly under the black shale in the railroad cut, one-fourth mile south of Huber, contains the following species:

Faunule of zone 1 of section 1367 A, near Huber, Ky.

[a, abundant; c, common; r, rare.]

1. Orthis sp. (r).
2. Camarotœchia tethys (c).
3. Tropidoleptus carinatus (r).
4. Spirifer cf. davisi (r).
5. Reticularia fimbriata (r).
6. Spirifer segmentus (r).
7. S. varicosus (r).
8. Ambocœlia umbonata (a).
9. Athyris spiriferoides (r).
10. Platyceras sp. (r).

The Niagara limestone is exposed at the roadside one-half mile south of Huber station. Fossils are scarce in it, and only the following were obtained:

Faunule of zone 1 of section 1367 B, near Huber, Ky.

[c, common; r, rare.]

1. Halysites catenulatus (c).
2. Cladopora sp. (c).
3. Conchidium cf. littoni (r).
4. C. sp. (r).

CLERMONT, BULLITT COUNTY, KY.

The Niagara limestone is quarried extensively at Clermont. The section exposed at one of the quarries is as follows:

Section 1368 A, at Clermont, Ky.

	Feet.
4. Devonian limestone with crinoid stems	3
3. Siliceous and dolomitic limestone	15–20
2. Blue shale	6
1. Hard blue limestone	15

Only a single species, *Calymene niagarensis*, was obtained from the bed (A1) below the blue shale.

The rocks in the quarry appear to contain few fossils. The following-named species, however, were collected from a fine-grained sandstone (1368 B), which outcrops in a ravine about one-fourth mile southeast of the quarry, and which appears to be the equivalent of the zone 3 of the quarry (1368 A).

Faunule of section 1368 B, near Clermont, Ky.

[a, abundant; c, common; r, rare.]

1. Zaphrentis cf. stokesi (c).
2. Cyathophyllum sp. (r).
3. Anastrophia internascens (r).
4. Conchidium cf. nysius (r).
5. Pentamerus oblongus (a).
6. Pentamerella sp. (r).
7. Rhynchonella stricklandi (r).
8. Atrypa reticularis (c).
9. A. reticularis var. niagarensis (c).
10. Spirifer radiatus (r).
11. Meristina maria (c).
12. Conocardium sp. (r).

Five miles northeast of Clermont the blue clay shale of the "knob stone" has been extensively denuded of soil and vegetation by "washes" on the slope of Deerlick Knob, exposing the following section:

Section 1368 C, at Deerlick Knob, Bullitt County, Kentucky.

	Feet.
5. Blue clay shale	35
4. Thin-bedded crinoidal limestone	5
3. Black shale	15
2. Covered	15
1. Limestone	3
	73

Faunule of zone 5 of section 1368 C, at Deerlick Knob, Kentucky.

[a, abundant; c, common; r, rare.]

1. Zaphrentis dalei (a).
2. Chonetes illinoisensis (r).
3. Productus semireticulatus (c).
4. Dielasma cf. bovidens (r).
5. Spirifer marionensis (r).
6. S. mortonanus (c).
7. S. sp. (r).
8. Athyris lamellosa (a).

The blue-clay shales containing this faunule are similar in lithologic as well as faunal characters to the New Providence shale of southern Indiana, of which they are the southern continuation.

The thin limestone of this section, at the top of the black shale, is of particular interest because it occupies the same stratigraphic horizon as the Rockford limestone 30 miles to the northwest, while it carries the lower "knob" (New Providence shale) fauna, which is entirely unlike that of the Rockford limestone. The following species were obtained at Deerlick Knob, Ky.:

Faunule of zone 4 of section 1368 C, at Deerlick Knob, Kentucky.

1. Rhipidomella oweni (abundant).
2. Spirifer mortonanus (common).
3. S. suborbicularis (common).

NEW HAVEN, NELSON COUNTY, KY.

The Devonian limestone was not seen at New Haven and, if present there, is very thin. The following section is exposed just west of the town, on the bank of Rolling Fork:

Section 1371 A, at New Haven, Ky.

	Feet.
3. Black shale	5
2. Covered	4
1. Dolomitic limestone	7

The dolomitic limestone, 1 of the above section, furnished the following Niagara species:

Faunule of zone 1 of section 1371 A, near New Haven, Kentucky.

1. Calymene niagarensis (common).
2. Dalmanites verrucosus (rare).

About 5 miles south of New Haven the following section is exposed along the pike at Muldrows Hill:

Section 1371 B, at Muldrows Hill, Kentucky.

	Feet.
9. Covered	10
8. Shaly limestone and shale	20
7. Shale	3–5
6. Limestone	20
5. Sandstone	9
4. Limestone	18
3. Bluish sandstone weathering shaly	40
2. Blue shaly sandstone	15
1. Shaly sandstone and shale	15

The above section shows the interpolation of the Harrodsburg ("Lower Carboniferous") limestone beds in the Knobstone sandstone.

The following section shows a similar interstratification of the limestone and Knobstone sandstone, 2 miles southwest of New Haven:

Section 1371 C, 2 miles south of New Haven, Ky.

	Ft.	In.
7. Shaly sandstone	8	0
6. Limestone	1	8
5. Gray sandy shale	10	0
4. Limestone and shale	18	0
3. Covered (mostly shale)	10	0
2. Iron-ore concretions	0	4
1. Black shale	10	0

It may be noted that the limestone at the top of the black shale in the Deerlick section (1368 C4) is represented in the above section only by a band of ferruginous concretions (1371 C2). No fossils were seen in the blue clay shale above the black shale except crinoid stems.

RILEY, MARION COUNTY, KY.

The Ordovician limestone outcrops about 100 yards northwest of Riley station with a dip of 10° to 15° southwest. The black shale is exposed in the cut at the station. A short distance northwest of the cut the shale rests unconformably on rocks which are probably of Niagara age. No fossils were found in them. The Ordovician outcrops northwest of Riley station (section 1372 A) afforded the following fossils:

Faunule of section 1372 A, northwest of Riley station.

1. Platystrophia crassa (rare).
2. P. lynx (common).
3. Murchisonia sp. (common).

In a sandy shale, just south of Riley station (section 1372 B), the following Knobstone faunule was collected:

Faunule of section 1372 B, south of Riley station, Kentucky.

[a, abundant; c, common; r, rare.]

1. Orthothetes crenistria (c).
2. Chonetes illinoisensis (a).
3. Productella shumardana (a).
4. Productus burlingtonensis (c).
5. P. punctatus (r).
6. P. semireticulatus (c).
7. Schizophoria sp. (r).
8. Camarotœchia sappho (r).
9. Spiriferina subelliptica (c).
10. Spirifer marionensis (r).
11. S. sp. (r).
12. Syringothyris texta (r).
13. Palæoneilo bedfordensis (r).
14. Macrodon cf. newarkensis (r).
15. Streblopteria sp. (r).
16. Cypricardinia sp. (c).

PARKSVILLE, BOYLE COUNTY, KY.

About three-fourths of a mile west of Parksville the black shale rests directly on the Ordovician, as shown in the accompanying section:

Section 1373 A, at Parksville, Ky.

	Feet.
2. Black shale	6
1. Soft blue shaly sandstone	4

The following species were collected from the shaly sandstone of the above section:

Faunule of zone 1 of section 1373 A, near Parksville, Ky.

1. Hebertella cf. occidentalis (rare).
2. Platystrophia laticosta (common).
3. P. lynx (common).

The black shale about Parksville is about 25 feet thick. The blue clay shale above it has its usual appearance. The Knobstone Hills, just south of the railroad, are about 150 feet high and have an abundance of loose limestone fragments on their summits. No beds of the limestone were seen in place.

At an old quarry in the "Knobstone" sandstone (section 1373 B), 1½ miles west of Parksville, the following species were collected:

Faunule of section 1373 B, near Parksville, Ky.

[c, common; r, rare.]

1. Orthothetes crenistria (c).
2. Productella cf. shumardana (r).
3. Productus alternatus (r).
4. P. semireticulatus (r).
5. Camarotœchia sp. (r).
6. Dielasma cf. formosa (c).
7. Spirifer keokuk (c).
8. S. lateralis (r).
9. Reticularia pseudolineata (c).
10. Eumetria marcyi (r).
11. Leiopteria sp. (r).
12. Platyceras bodensis (r).

JUNCTION CITY, BOYLE COUNTY, KY.

The black shale outcrops at a number of places in the vicinity of Junction City. It extends below drainage, so that the underlying beds were not seen. The following section indicates the stratigraphic relations:

Section 1374 A, at Lone Knob, near Junction City, Ky.

	Feet.
3. Shaly sandstone	60
2. Blue clay shale	80
1. Black shale	15

CRAB ORCHARD, LINCOLN COUNTY, KY.

The Devonian limestone appears to be entirely absent in the vicinity of Crab Orchard. The following connected section includes the lowest beds observed in the vicinity of the springs and those outcropping in the knobs southwest of town:

Section 1375 A, near Crab Orchard, Ky.

	Feet.
5. Shaly sandstone ("Knobstone"	50
4. Shaly crinoidal limestone	3-4
3. Shaly sandstone and clay shale (partly covered)	100
2. Black shale	35
1. Buff to brownish fine-grained sandstone	10

No fossils were found in the fine-grained sandstone below the black shale.

The shaly sandstone (zone 5 of section 1375 A), 2 miles southwest of Crab Orchard, furnished the following faunule:

Faunule of zone 5 of section 1375 A, near Crab Orchard, Ky.

[c, common; r, rare.]

1. Zaphrentis sp. (r).
2. Chonetes illinoisensis (c).
3. Productus sp. (r).
4. Camarotœchia cf. contracta (r).
5. Spiriferina subelliptica (c).
6. Spirifer mortonanus (c).
7. S. suborbicularis (c).
8. Reticularia pseudolineata (r).
9. Syringothyris texta (c).
10. Ptychospira cf. sexplicata (r).
11. Athyris lamellosa (c).
12. Sphenotus sp. (r).
13. Edmondia sp. nov. (r).
14. Conocardium pulchellum (c).
15. Cypricardinia sp. (c).
16. Loxonema sp. nov. (r).
17. Platyceras cf. herzeri (r).
18. P. sp. (c).
19. Proetus auriculatus (r).
20. Phaëthonides sp. (r).

SECTIONS IN VIRGINIA AND WEST VIRGINIA.

By E. M. Kindle.

The faunas from Virginia and West Virginia were collected in part by H. S. Williams in 1895, and in part by E. M. Kindle in 1898.

The Virginia and West Virginia localities examined furnished faunules from the following localities, viz:

Sections in Virginia and West Virginia.

1376. Bigstone Gap, Wise County, Va.
   A. East Fork of Powell River, above flouring mill.
   B. Cuttings of Southern Railway, northeast of Bigstone Gap.
   C. On bank of Powell River, east side village at woolen mill.
   D. South bank of river.
   E. Loose in fields and talus heaps of rock exposure at Little Stone Gap.

1377 A. Big Moccasin Gap, Va., between the railroad switch at the gap and the limestone southeast of Doctor Wallace's residence.

1379. Hicksville, Bland County, Va.
   A1. About 1½ miles above Hicksville in small ravine on Mr. Hornbarger's land.
   A2. A few hundred yards east of 1379 A1 in bed of Kimberling Creek.
   A3. One-half mile north of Hicksville.
   A4. One mile east of Hicksville, near summit of Brushy Mountain.
   B. On the Bluefield and Bland road, 300 yards southeast of summit of Brushy Mountain, and about 2 miles southwest of A4.
   C. West of Point Pleasant, near top of Brushy Mountain.
   X. On the Bluefield and Bland road, about 1¼ miles south of Rocky Gap post-office.

1380. White Sulphur Springs, W. Va.
   A. Hotel grounds.
   B. West end of tunnel and cuts along railroad southeast of White Sulphur Springs.
   C. West end of long cut 1½ miles southeast of White Sulphur Springs.
   D. Side of railroad three-fourths mile west of White Sulphur Springs.
   E. Wagon road 1¼ miles west of White Sulphur Springs.
   F. One-half mile east of Howard station.

1381 A. Caldwell, W. Va.

1382. Covington, Va.
   A. East of Caldwell, W. Va.
   B. One-half mile southeast of blast furnace, on north bank of Jackson River.
   C. West bank of Jackson River, one-fourth mile south of Chesapeake and Ohio Railway bridge at Covington.

1383 A. Northwest of Hot Springs, Va., along the Chesapeake and Ohio Railway.

1384 A. Near the Chesapeake and Ohio Railway bridge west of Clifton Forge, Va.

BIGSTONE GAP, WISE COUNTY, VA.

The Hancock limestone and the Grainger shale[a] are well exposed just northeast of Bigstone Gap, between the East Fork of Powell River and the Virginia and Southwestern Railway. On the East Fork of Powell River, just above the flouring mill, the Hancock limestone outcrops with a strike of S. 80° W., and a dip of 60° N. Above the limestone are about 50 feet of coarse sandstone.

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[a] Estillville sheet, Geol. Atlas U. S.

Section 1376 A, on East Fork of Powell River, above flouring mill.

		Feet.
2.	Coarse sandstone ("Oriskany")	50
1.	Hancock limestone, top of	10

Faunule of zone 1 of section 1376 A, on East Fork of Powell River.

[c, common; r, rare.]

1. Stropheodonta beckii (r).
2. S. cf. planulata (r).
3. Strophonella cavumbona (r).
4. Leptæna rhomboidalis (c).
5. Rhipidomella sp. (r).
6. Gypidula pseudogaleata (r).
7. Rhynchonella altiplicata (c).
8. Rensselæria mutabilis (r).
9. Cyrtina cf. dalmani (r).
10. Nucleospira sp. (r).
11. Meristella lævis (c).
12. M. subquadrata (r).
13. Platyceras sp. (r).
14. Tentaculites elongatus (r).

Faunule of zone 2 of section 1376 A, on East Fork of Powell River.

[a, abundant; c, common; r, rare.]

1. Zaphrentis sp. (r).
2. Favosites sp. (r).
3. Strophonella cavumbona (r).
4. Leptæna rhomboidalis (c).
5. Orthothetes woolworthanus (r).
6. Dalmanella cf. planiconvexa (r).
7. Rhipidomella oblata (c).
8. Camarotœchia ventricosa (a).
9. Cyrtina cf. dalmani (c).
10. Spirifer cyclopterus (a).
11. Meristella lævis (c).
12. Platyceras pyramidatum (r).
13. Tentaculites elongatus (r).
14. Proetus protuberans (r).

At the side of the Southern Railway, northeast of Bigstone Gap, the sandstone lies upon the limestone, and across the river to the north the black shale appears, given in the section below. The succession was clear, but the exact thickness of the beds was not evident.

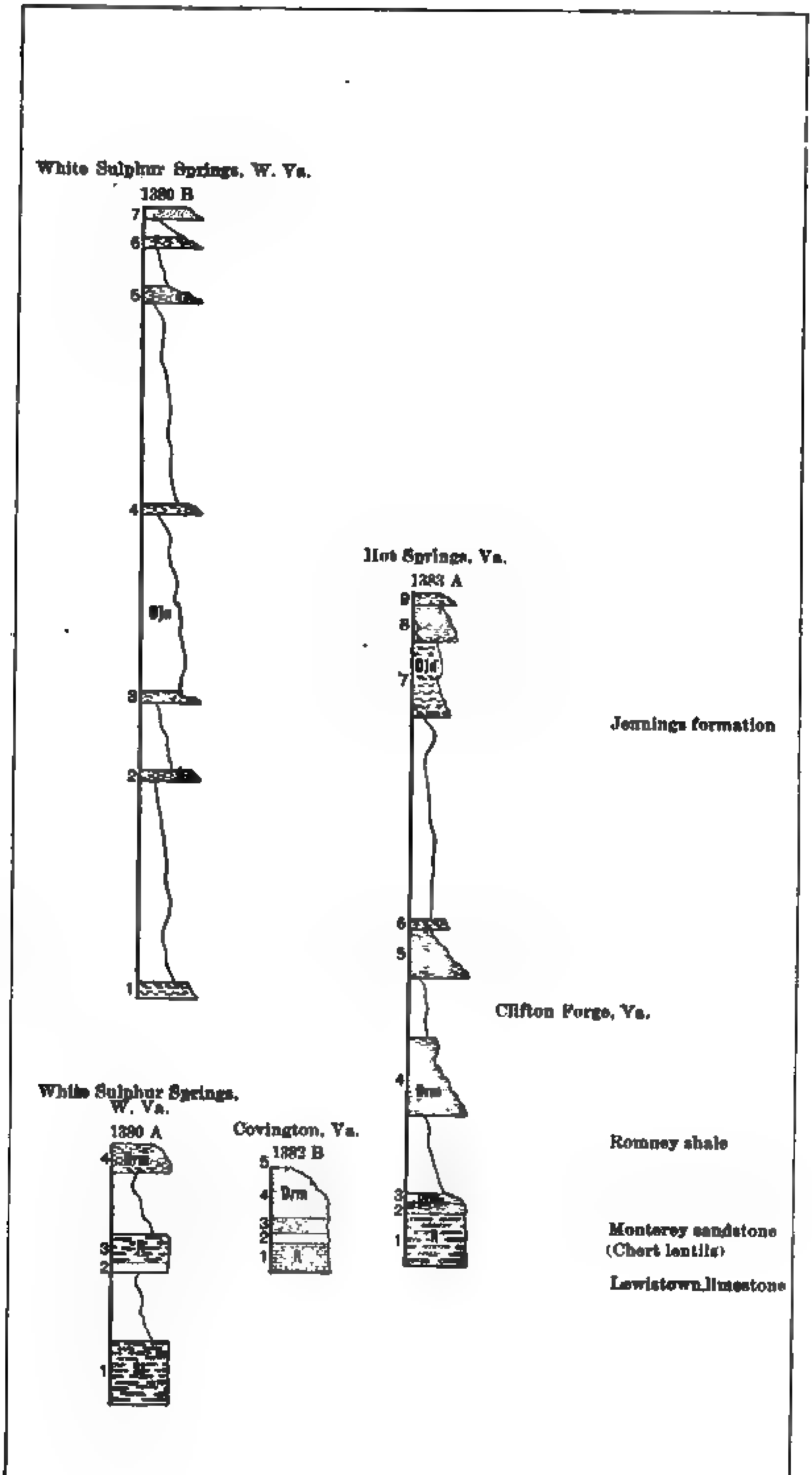
Section 1376 B, on Southern Railway, near Bigstone Gap.

3. Black shale.
2. Sandy and cherty beds ("Oriskany").
1. Hancock limestone.

Faunule of zone 2 of section 1376 B, on Southern Railway, near Bigstone Gap.

[a, abundant; c, common; r, rare.]

1. Zaphrentis sp. (r).
2. Aulopora sp. (r).
3. Aspidocrinus scutelliformis (r).
4. Stictopora sp. (r).
5. Polypora sp. (r).
6. Roemerella cf. grandis (r).
7. Stropheodonta lincklæni (r).
8. S. magnifica (c).
9. S. beckii (c).
10. Strophonella cavumbona (c).
11. Leptæna rhomboidalis (a).
12. Orthothetes woolworthanus (c).
13. Dalmanella cf. planiconvexa (r).
14. Rhipidomella oblata (a).
15. Gypidula pseudogaleata (r).
16. Rhynchotrema formosum (r).
17. Camarotœchia ventricosa (a).
18. Uncinulus campbellanus (r).
19. Rhynchonella acutiplicata (c).
20. Rensselæria mutabilis (r).
21. R. sp. (r).
22. Atrypa reticularis (r).
23. Cyrtina dalmani (c).
24. Spirifer cyclopterus (a).
25. S. sp. (r).
26. Meristella cf. bella (r).
27. M. subquadrata (c).
28. M. sp. (r).
29. Avicula communis (r).
30. Loxonema sp. (r).
31. Holopea antiqua (r).
32. Proetus sp. (r).
33. Homalonotus sp. (r).
34. Phacops cf. cristata (r).
35. P. logani (c).



SECTIONS IN VIRGINIA AND WEST VIRGINIA.

In the bed of the ravine just north of the sand and cherty beds (1376 B2), the black Chattanooga shale (1376 B3) is exposed. It has a deep black color and contains an abundant fauna composed of *Lingula ligea* and *Schizobolus concentricus.*

The sandy beds of the Hancock limestone are well exposed about the iron furnace, and just north of the subterranean mouth of Wild Cat Creek. Collections from this locality were lost in transit.

On bank of Powell River by the woolen mill east of the village a section (1376 C) yielded the following fossils:

Faunule of section 1376 C, on Powell River.

[c, common; r, rare.]

1. Calceola cf. plicata (r).
2. Leptæna rhomboidalis (r).
3. Rhipidomella oblata (r).
4. Gypidula pseudogaleata (c).
5. Camarotœchia ventricosa (c).
6. Rhynchonella acutiplicata (r).
7. Spirifer cumberlandiæ (c).
8. S. cyclopterus (r).
9. Reticularia cf. fimbriata (r).
10. Meristella subquadrata (c).
11. Phacops cristata (r).
12. Dalmanites cf. anchiops (r).
13. D. pleuroptyx (r).

Along the river bank on the south side Mr. Williams collected from the reddish sandstone beds (1376 D), immediately below the Mississippian ("Lower Carboniferous") limestone, a fossil sponge which appears to be identical with the species described from the Waverly of Pennsylvania as *Ectenodictya inflexa.*

From rocks in the fields and in place at Little Stone Gap (1376 E) Mr. Williams collected species representing the fauna from the coarse sandstone beds underlying the black shale.

Faunule of section 1376 E, at Little Stone Gap, Va.

[c, common; r, rare.]

1. Zaphrentis sp. (r).
2. Cyathophyllum sp. (r).
3. Cystiphyllum sp. (r).
4. Favosites sp. (r).
5. Cladopora sp. (r).
6. Gypidula pseudogaleata (c).
7. Atrypa reticularis (r).
8. Spirifer cyclopterus (r).
9. S. perlamellosus var. (r).
10. Meristella subquadrata (c).
11. Cyrtolites sp. (r).
12. Platyceras cf. gebhardi (c).
13. Tentaculites sp. (r).
14. Dalmanites cf. pleuroptyx (r).

BIG MOCCASIN GAP, VA.

At Big Moccasin Gap the rocks dip from 30° to 40° SE. The strike is about S. 20° W., or approximately the direction of Clinch Mountain. The following section is based on the nearly continuous outcrops seen between the railroad switch at Big Moccasin Gap and the limestone southeast of Doctor Wallace's residence.

Section 1377 A, at Big Moccasin Gap, Va.

	Feet.
7. Limestone and shale (Carboniferous)	
6. Soft yellowish clay and crumbling sandstone	100
5. Hard, drab-colored sandy shale and sandstone	40
4. Conglomerate band near top of 3′ } 3. Hard, bluish-gray to drab sandy shale }	60
2. Black shale, varying to gray, and much crushed and folded	150
1. Tough quartzitic fine-grained sandstone	75

In the Estillville folio, 2 is called the Chattanooga black shale, and 3 to 6 are assigned to the Grainger shale. The lowest fauna obtained from the section is from the lower part of 3, about 20 feet above the black shale.

Faunule of zone 3 of section 1377 A, at Big Moccasin Gap, Virginia.

[c, common; r, rare.]

1. Zaphrentis sp. (r).
2. Crinoid stems (c).
3. Fenestella sp. (r).
4. Lingula gannensis (r).
5. Orbiculoidea sp. (c).
6. Chonetes sp. (r).
7. Productus cora var. (r).
8. P. cf. semireticulatus (r).
9. P. cf. wortheni (c).
10. P. sp. (r).
11. Camarotœchia sp. (r).
12. Spirifer cf. marionensis (c).
13. Reticularia pseudolineata (c).
14. Syringothyris carteri (r).
15. Athyris lamellosa (c).
16. Conularia sp. (r).

About 40 feet above the last zone a rich fauna occurs in the thin bands of ferruginous conglomerate which outcrop at the roadside nearly opposite the residence of Doctor Wallace. This is unquestionably a Knobstone or Waverly fauna. Some of the species are identical with those from the southern Indiana Knobstone. The following species were obtained:

Faunule of zone 4 of section 1377 A, at Big Moccasin Gap, Virginia.

[a, abundant; c, common; r, rare.]

1. Chonetes sp. (a).
2. Camarophoria sp.
3. Dielasma sp. nov. (c).
4. Spiriferina cf. solidirostris (a).
5. Spirifer sp. (c).
6. Reticularia pseudolineata (r).
7. Syringothyris sp. (c).
8. Glossites sp. (r).
9. Spathella sp. (r).
10. Edmondia sp. (r).
11. Nucula sp. (r).
12. Palæoneilo perplana (a).
13. P. sulcatina (a).
14. P. sp.
15. Nuculana spatulata (r).
16. Leptodesma sp. (r).
17. Schizodus sp. (r).
18. Bellerophon sp. (a).
19. B. sp. (a).
20. Pleurotomaria stulta (r).
21. P. sp. (a).
22. Loxonema sp. (c).
23. Platyceras sp. (r).
24. Orthoceras sp. (c).
25. O. sp. (c).
26. Prolecanites greeni (r).
27. Phaëthonides sp. (r).

About 30 or 40 feet above the last zone, the following species were collected from a shaly dark-gray sandstone, about 100 yards southeast of Doctor Wallace's house:

Faunule of zone 5 of section 1877 A, near Big Moccasin Gap, Virginia.

[c, common; r, rare.]

1. Lepidodendron sp. (r).
2. Crinoid stems (r).
3. Lingulodiscina newberryi (r).
4. Productus sp. (c).
5. Camarotœchia sp. (r).
6. Spirifer keokuk (c).
7. Sphenotus flavius (c).
8. Edmondia sp. (r).
9. Palæoneilo bedfordensis (c).
10. Macrodon sp. (r).
11. Pinna sp. (r).
12. Schizodus sp. (r).
13. Actinopteria sp. (c).
14. Crenipecten sp. (r).
15. Modiomorpha sp. (r).
16. Bellerophon sp. (r).
17. Conularia newberryi (r).

The soft yellow arenaceous sandstone (6) between the last station and the Mississippian ("Lower Carboniferous") limestone afforded the following fossils: *Productus cora*, *Camarotœchia contracta*. Both these forms are common.

BLAND COUNTY, VA.

In Bland County collections were made in the valleys of Wolf and Kimberling creeks and at the summit of Brushy Mountain, east of Hicksville post-office.

Wolf and Kimberling creeks have cut their valleys into the easily eroded black shale (the Romney shale of the Pocahontas folio), which is estimated by Campbell[a] to have a thickness of from 400 to 600 feet. This shale dips sharply SE. and has the deep black color and finely laminated appearance generally characteristic of the black shale. Toward the top it merges into a hard, sandy, greenish-gray shale. The change is not abrupt, but beyond the limits of the 20 or 30 feet of passage beds the appearance and composition of the two formations are quite distinct. Campbell[b] regards the rocks in this region, between the Romney shale and the base of the Pennsylvanian ("Coal Measures,") as a lithologic unit, and has given them the name of Kimberling shale.

While it is difficult to separate the upper from the lower portion of this series on lithologic grounds, the fossils show that two distinct time periods are represented. The Mississippian ("Lower Carboniferous") limestone is absent here, and the transition from the Kimberling shale to the Pennsylvanian is made with such imperceptible changes in the appearance of the rocks that the limits of the two are difficult to sharply define.

Along the southeastern foot of Round Mountain a heavy bed of dark-gray chert, with occasional interstratified thin beds of greenish or yellowish sandstone lies just below the Romney shale. This is a

[a] Campbell, M. R., Description of Pocahontas district: Geol. Atlas U. S., folio 26, U. S. Geol. Survey, 1896.

[b] Ibid.

portion of the Giles formation of Campbell. The chert bed is nearly everywhere hidden by the loose fragments produced by weathering, so that its thickness was not ascertained.

General section 1379, near Hicksville, Va.

C. Thin-bedded sandstone. }
B. Shaly sandstone. } Kimberling shale.
A4. Shaly sandstone. }
A3. Dark-colored sandy shale, about 75 feet above A2.
A2. Black shale (Romney shale).
A1. Sandstone and chert (Giles formation).

About 1½ miles above Hicksville, in a small ravine on Mr. Hornbarger's land, the following fossils were obtained from a few inches of sandstone (1379 A1) interbedded with chert.

Faunule of zone 1 of section 1379 A, near Hicksville, Va.

[a, abundant; c, common; r, rare.]

1. Pholidops cf. arenaria (c).
2. Stropheodonta sp. (r).
3. Leptæna rhomboidalis (r).
4. Chonetes sp. nov. (r).
5. Anoplia nucleata (c).
6. Orthis sp. (r).
7. Amphigenia cf. elongata (r).
8. Rhynchonella sp. (r).
9. Spirifer cumberlandiæ (a).
10. S. sp. (c).
11. Ambocœlia sp. (r).
12. Nucleospira sp. (r).
13. Anoplotheca cf. dichotoma (r).
14. Platyostoma ventricosum (r).
15. Tentaculites elongatus (r).

A few hundred yards east of 1379 A1, in the bed of Kimberling Creek, *Schizobolus truncatus* is common in the Romney or black shale (1379 A2). The same species is also found in the black shale in bank of creek, one-half mile south of Hicksville, Va. The drab or greenish sandy shale which follows the Romney shale appears to be barren of fossils at most localities.

About one-half mile north of Hicksville (1379 A3) a few specimens of *Palæoneilo brevis* and *Goniatites* sp. were found just east of the ford and about half way up the face of the cliff. The horizon of this station is probably 100 feet above the top of the typical Romney shale.

On Brushy Mountain, east of Hicksville, no fossils were found above station 1379 A3, until within 100 feet of the summit (1379 A4), where a rich Chemung fauna was discovered in the Kimberling shale.

Faunule of zone 4 of section 1379 A, near the summit of Brushy Mountain, Virginia.

[a, abundant; c, common; r, rare.]

1. Orbiculoidea sp. (r).
2. Chonetes scitulus (a).
3. Productella sp. (r).
4. Camarotœchia contracta (a).
5. C. sappho (r).
6. Spirifer disjunctus (c).
7. Grammysia subarcuata (c).
8. Sphenotus contractus (r).
9. Leptodesma matheri (r).
10. L. potens (a).
11. L. potens var. juvene (r).
12. Mytilarca chemungensis (c).
13. Nyassa cf. arguta (r).
14. Modiomorpha subalata var. chemungensis.
15. Goniophora chemungensis (r).
16. Euomphalus sp. (r).

The Chemung fauna may be found at or near the summit of Brushy Mountain at most localities in Bland County. About 2 miles southwest of the last station and 300 yards southeast of the summit of Brushy Mountain, on the Bluefield and Bland road (1379 B), the following species were found:

Faunule of section 1379 B, on Brushy Mountain, Virginia.

[a, abundant; c, common; r, rare.]

1. Productella hirsuta (c).
2. Dalmanella tenuilineata (r).
3. Camarotœchia cf. contracta (c).
4. C. duplicata (a).
5. Ambocœlia umbonata (c).
6. Grammysia subarcuata (r).
7. Edmondia cf. philipi (r).
8. Leptodesma cf. potens (r).
9. Leptodesma sp. (r).
10. Mytilarca chemungensis (c).
11. Nyassa cf. arguta (r).
12. Modiomorpha subalata var. chemungensis (r).
13. M. sp. (r).
14. Orthoceras sp. (r).

Near the top of Brushy Mountain west of Point Pleasant (1379 C) the following species occur:

Faunule of section 1379 C, on Brushy Mountain, Virginia.

[a, abundant; c, common; r, rare.]

1. Orbiculoidea sp. (r).
2. Chonetes setigerus (a).
3. Productella lachrymosa var. stigmata (c).
4. Camarotœchia contracta (c).
5. C. duplicata (r).
6. Spirifer disjunctus (r).
7. Grammysia cf. bisulcata (r).
8. Sphenotus sp. (r).
9. Leptodesma potens (r).
10. L. potens var. juvene (r).
11. Mytilarca regularis (r).
12. Aviculopecten sp. (r).

About 1¼ miles south of Rockygap post-office, on the Bluefield-Bland road, the following fossils were collected from some detached masses of coarse sandstone (1379 X). The stratigraphic position of this sandstone was not certainly ascertained, but it appears to belong to the Giles formation:

Faunule of section 1379 X, near Rockygap, Va.

1. Aspidocrinus scutelliformis (abundant).
2. Spirifer cyclopterus (rare).
3. Meristella sp.

WHITE SULPHUR SPRINGS, W. VA.

In the vicinity of White Sulphur Springs the channel of Howards Creek follows approximately the axis of an anticline. The lowest beds exposed here are the black and gray cherts, which outcrop along the bank of this stream at the northwest side of the White Sulphur Springs Hotel grounds. From this point the dip of the beds is toward the southeast. From White Sulphur Springs station to Tuckahoe the

Chesapeake and Ohio Railway crosses the strike of the beds nearly at right angles. The numerous cuts along this section of the road, together with the outcrops on the hotel grounds, afford a section from the black cherts nearly through the shales and sandstones of the Chemung. The following section includes all the outcrops observed on the west side of the White Sulphur Springs Hotel grounds:

Section 1380 A, on White Sulphur Springs Hotel grounds, West Virginia.

	Feet.
4. Black shale ("Romney")	30
Concealed	30
3. Gray chert	25
2. Coarse sandstone ("Oriskany")	6
Concealed	60
1. Black chert	50
	201

The chert (1) in this section appears to be entirely barren of fossils.

The sandstone (2) in the rear of Alabama row, White Sulphur Springs Hotel, contains the following species:

Faunule of zone 2 of section 1380 A, at White Sulphur Springs Hotel, West Virginia.

[a, abundant; c, common; r, rare.]

1. Crinoid plate.
2. Hipparionyx proximus (r).
3. Orthis sp. (c).
4. Dalmanella cf. planiconvexa (c).
5. Rhipidomella musculosa (a).
6. Eatonia peculiaris (c).
7. E. pumila (c).
8. Rhynchonella oblata (r).
9. Rensselæria cf. marylandica (r).
10. R. ovoides (a).
11. Beachia cf. suessana (c).
12. Leptocœlia sp. (c).
13. Spirifer arenosus (a).
14. S. murchisoni (c).
15. S. sp. (r).
16. Meristella lata (r).
17. Platyceras cf. gebhardi (r).
18. P. ventricosum (r).

No fossils were discovered in the gray chert (3). On the hotel grounds, at the east end of Baltimore row, numerous specimens of *Schizobolus truncatus* were found in the black ("Romney") shale (4).

The black carbonaceous shale containing *Schizobolus truncatus* changes gradually to a dark-gray or blackish sandy shale (Jennings), containing the fauna listed below, which is seen at the west end of tunnel, White Sulphur Springs (1380 B):

Section 1380 B, along railroad from west end of tunnel to long cut 1¼ miles southeast of White Sulphur Springs, W. Va.

	Feet.
7. Greenish sandstone and shale	50
6. Greenish shale	200
5. Shale, northwest end of cut below tool house	100
4. Green to gray shale	140
3. Greenish shale	60
2. Greenish shale	160
1. Sandy shale at west end of tunnel	150

Faunule of zone 1 of section 1380 B, at west end of tunnel, White Sulphur Springs, W. Va.

[a, abundant; c, common; r, rare.]

1. Paracardium doris (r).
2. Buchiola speciosa (a).
3. Palæoneilo brevis (r).
4. Orthoceras bebryx var. cayuga (r).
5. Parodiceras discoideum (c).
6. Goniatites sp. (c).

The beds containing this Nunda (*Buchiola speciosa*) fauna are probably 150 feet thick. They are followed by 100 feet or more of soft greenish clay shale in which no fossils were found.

The following zones are exposed in the cuts along the railroad southeast of White Sulphur Springs. About 150 feet above the last zone the greenish shale, 1380 B2, contains the following species:

Faunule of zone 2 of section 1380 B, near White Sulphur Springs, W. Va.

[a, abundant; c, common; r, rare.]

1. Orbiculoidea neglecta (c).
2. Leiorhynchus laura (a).
3. Delthyris mesicostalis (r).
4. Ambocœlia gregaria (a).

About 60 feet above the last zone is greenish shale containing the following species:

Faunule of zone 3 of section 1380 B, near White Sulphur Spring, W. Va.

[a, abundant; c, common; r, rare.]

1. Craniella cf. hamiltoniæ (r).
2. Stropheodonta (Douvillina) mucronata.[a] (a).
3. Orthothetes chemungensis (r).
4. Productella cf. subalata (r).
5. P. sp. (r).
6. Dalmanella tioga (a).
7. Camarotœchia sappho (c).
8. C. sp. (r).
9. Leiorhynchus laura (a).
10. Delthyris mesicostalis (c).
11. Ambocœlia gregaria (a).
12. Edmondia cf. rhomboidea (r).
13. Palæoneilo sp. (r).
14. Mytilarca chemungensis (r).
15. Actinopteria boydi (c).
16. Aviculopecten sp. (r).
17. Lyriopecten cf. tricostatus (r).

About 140 feet above 1380 B3 is a gray to greenish shale which contains the following fossils:

[a] It is important to notice that the species described by Hall in the fourth volume of Paleontology of New York (1867, p. 110, pl. 19, figs. 1-5) under the name *Strophodonta cayuta* n. s., and afterwards described generally in literature under that name, was described by Conrad in 1842 (Jour. Acad. Nat. Sci., Philadelphia, viii, p. 257, pl. 14, fig. 10) under the name *Strophomena mucronata*, and referred to the proper fauna (Chemung) to which it belongs and cited from a typical Chemung locality, Chemung Narrows, in southern New York. The species described by Hall in 1867 under the name *Strophodonta mucronata* (see p. 111, pl. 15, figs. 13, 14) and cited as the same as Conrad's species is actually distinct specifically and at least subgenerically. It belongs to the subgenus *Leptostrophia* of Hall and Clarke, and was previously correctly figured, but not described, by Vanuxem in 1842 (Geol. New York Rept. Third Dist., 1842, p. 174, fig. 1) under Phillip's name *Strophomena interstrialis*. As Phillip's species is also subgenerically distinct from it, the specific name *interstrialis* is available in the combination *Leptostrophia interstrialis* Vanuxem. Phillip's species would be *Douvillina interstrialis*. *Stropheodonta* (*Leptostrophia*) *interstrialis* Vanuxem is abundant in the Ithaca formation, and, though it may occur in the Chemung, is there extremely rare. On the other hand, *Stropheodonta* (*Douvillina*) *mucronata* Conrad does not, so far as thorough examination has revealed, occur until the Chemung epoch, and is a diagnostic Chemung species.—H. S. W.

Faunule of zone 4 of section 1380 B, near White Sulphur Springs, W. Va.

[a, abundant; c, common; r, rare.]

1. Zaphrentis sp. (r).
2. Lingula cf. ligea (r).
3. Stropheodonta (Douvillina) mucronata (c).
4. S. demissa (r).
5. Orthothetes cf. chemungensis (c).
6. Schizophoria striatula (r).
7. Dalmanella tioga[a] (c).
8. Atrypa hystrix (r)
9. A. reticularis (a).
10. A. spinosa (a).
11. Cyrtina hamiltonensis (c).
12. Spirifer disjunctus (c).
13. Actinopteria perstrialis (r).
14. A. cf. eta (r).
15. Pterinea (Vertumnia) reversa (c).
16. Pterinopecten sp. (r).

At the northwest end of cut below tool house, near White Sulphur Springs, with the following faunule, was found:

Faunule of zone 5 of section 1380 B, near White Sulphur Springs, W. Va.

[a, abundant; c, common; r, rare.]

1. Stropheodonta (Douvillina) mucronata (a).
2. Strophonella cælata (r).
3. Productella hirsuta (a).
4. Schizophoria striatula (c).
5. Leiorhynchus laura (r).
6. Atrypa spinosa (r).
7. Cyrtina hamiltonensis (r).
8. Spirifer disjunctus (a).
9. Ambocœlia gregaria (c).
10. Phthonia sp. (r).
11. Palæoneilo bisulcata (a).
12. P. filosa (r).
13. P. plana (r).
14. Leptodesma lichas (c).
15. Lyriopecten tricostatus (r).
16. Cypricardella sp. (r).

In cuts just north of tool house, probably 200 feet above B4, greenish shales (B6) yielded the following faunule:

Faunule of zone 6 of section 1380 B, near White Sulphur Springs, W. Va.

[a, abundant; c, common; r, rare.]

1. Orbiculoidea sp. (r).
2. Stropheodonta (Douvillina) mucronata (c).
3. Productella hirsuta (a).
4. Dalmanella tenuilineata (c).
5. Atrypa spinosa (c).
6. Cyrtina hamiltonensis (r).
7. Spirifer disjunctus (a).
8. Ambocœlia gregaria (a).
9. Spathella sp. (r).
10. Edmondia philipi (r).
11. Palæoneilo bisulcata (r).
12. P. filosa (r).
13. Macrodon cf. chemungensis (r).
14. Leptodesma complanatum (r).
15. L. lichas (r).
16. L. protextum (r).
17. Actinopteria sp. (r).
18. Aviculopecten sp. (r).

[a] The species described by Hall in 1843 as *Orthis carinata* (Geol. New York, Rept. Fourth Dist., p. 267, fig. 1) and the species described by the same author under the name *Orthis interlineata* (non-Sowerby) and afterwards more fully described as *Orthis tioga* (Pal. New York, IV, 1867, p. 59, pl. 8, figs. 20–29) both belong to the genus *Dalmanella* Hall and Clarke (Pal. New York, VIII, Pt. I, 1892, pp. 205, 223), and do not belong to the genus *Schizophoria* King, to which Hall and Clarke referred it in 1892 (Pal. New York, VIII, Pt. I, 1892, pp. 213, 226, pl. 6, fig. 22, and pp. 212, 226, pl. 6, figs. 17, 18). Mr. Schuchert, in quoting the species (Bull. U. S. Geol. Survey No. 87, 1897, pp. 373, 375) has evidently overlooked this fact. The oversight may have arisen from a confusion of the valves. The carinated valve of *Dalmanella* is the pedicle valve, while the convex valve of *Schizophoria* is the brachial. Examination of the muscular scars will at once reveal the difference in the field. The Schizophorias are common below the Chemung, but they are rare in the Chemung until the upper part is reached, while the Dalmanellas are among the first forms to appear at the incoming of the Chemung fauna, and they are conspicuous representatives of the Chemung fauna.—H. S. W.

Greenish sandstone and shale (1380 B7) opposite the milepost contained the following species:

Faunule of zone 7 of section 1380 B, near White Sulphur Springs, W. Va.

[a, abundant; c, common; r, rare.]

1. Orthothetes chemungensis (c).
2. Productella lachrymosa (a).
3. Dalmanella tenuilineata (r).
4. Schizophoria striatula (c).
5. Camarotœchia contracta (c).
6. Leiorhynchus laura (r).
7. Spirifer disjunctus (a).
8. Delthyris mesicostalis (a).

Near the milepost the road crosses the axis of a syncline, so that beyond this point the beds reverse their dip. This makes it impossible to indicate with precision the stratigraphic relation of the stations below and those already given.

In west end of long cut (1380 B), 1½ miles southeast of White Sulphur Springs, is the following section:

Section 1380 C, along railroad, 1½ miles southeast of White Sulphur Springs, the rocks dipping westward.

3. Loose specimens along track, 1½ miles beyond White Sulphur Springs.
2. Dark bluish-gray sandstone at east end of long cut.
1. Dark, sandy shales at west end of cut.

The exact relation, in thickness, of these beds to each other was not ascertained. The dark sandy shales (1) are about 60 feet thick and dip W. 25°. They contain the following faunule:

Faunule of zone 1 of section 1380 C, near White Sulphur Springs, W. Va.

[a, abundant; c, common; r, rare.]

1. Stropheodonta (Douvillina) mucronata (a).
2. S. demissa (r).
3. Chonetes scitulus (a).
4. Productella cf. spinulicosta (c).
5. Dalmanella tioga (r).
6. Leiorhynchus mesicostale (c).
7. Atrypa spinosa (r).
8. Grammysia sp. (r).
9. Edmondia subovata (r).
10. E. transversa (r).
11. Buchiola speciosa (r).
12. Palæoneilo brevis (a).
13. P. constricta (r).
14. P. filosa (r).
15. P. sp. (r).
16. Leda diversa (r).
17. Macrodon sp. (r).
18. Leptodesma sp. (r).
19. Mytilarca chemungensis (r).
20. Aviculopecten sp. (r).
21. Crenipecten sp. (c).
22. Pleurotomaria sp. (r).
23. Coleolus sp.
24. Goniatites sp. (r).
25. Echinocaris sp. (r).

At the east end of long cut mentioned above is a dark, bluish-gray, shaly sandstone (1380 C2), which yielded the following faunule:

Faunule of zone 2 of section 1380 C, near White Sulphur Springs, W. Va.

[c, common; r, rare.]

1. Stropheodonta (Douvillina) mucronata (r).
2. S. demissa (c).
3. Chonetes scitulus (c).
4. Productella hirsuta (r).
5. Atrypa reticularis (r).
6. A. spinosa (a).
7. Spirifer disjunctus (r).
8. Sphenotus undatus (r).
9. Palæoneilo brevis (r).
10. Pterinopecten sp. (r).

Loose specimens on the southwest side of the Chesapeake and Ohio Railway track, 1½ miles southeast of White Sulphur Springs, furnished the following species:

Faunule of zone 3 of section 1380 C, near White Sulphur Springs, W. Va.

[c, common; r, rare.]

1. Stropheodonta (Douvillina) mucronata (c).
2. Orthothetes chemungensis (r).
3. Chonetes scitulus (c).
4. Productella lachrymosa (c).
5. Schizophoria striatula (r).
6. Leiorhynchus mesicostale (r).
7. Spirifer disjunctus (r).
8. Delthyris mesicostalis (c).
9. Ambocœlia gregaria (r).
10. Sphenotus sp. (r).
11. Leptodesma extenuatum (r).
12. L. naviforme (r).
13. L. potens var. juvene (r).
14. Aviculopecten sp. (r).
15. Modiomorpha quadrula (r).
16. Loxonema sp. (r).
17. Phacops rana (r).

Between White Sulphur Springs and Caldwell the following material was obtained:

Faunule of section 1380 D, three-fourths of a mile west of White Sulphur Springs.

1. Buchiola speciosa (abundant).
2. Plethospira socialis (abundant).

Faunule of section 1380 E, at side of wagon road, 1¼ miles west of White Sulphur Springs.

1. Buchiola speciosa (common).
2. Panenka sp. (rare).
3. Styliola fissurella (abundant).

Faunule of section 1380 F, one-half mile east of Howard station.

[a, abundant; c, common; r, rare.]

1. Orthothetes chemungensis var. arctostriatus (a).
2. Chonetes scitulus (a).
3. Camarotœchia cf. contracta (r).
4. Spirifer disjunctus (r).
5. Leptodesma rogersi (c).

The higher members of the series, which follow the fossiliferous beds of 1380 E, appear to be entirely barren of fossils. The red, green, and black shales, which constitute these higher beds, are well exposed near Caldwell, W. Va., station 1381 A.

CALDWELL, GREENBRIER COUNTY, W. VA.

The following section was noted in the cut just east of Caldwell:

Section 1381 A, east of Caldwell, W. Va.

	Ft.	In.
9. Alternating green and reddish shale	40	0
8. Blue to black or green shale	0–4	0
7. Greenish shale	4 to 10	0
6. Sandstone	6	0
5. Soft greenish-blue shale	1	6
4. Hard green shale	9	0
3. Blue to black banded shale	5	0
2. Bluish-green clay, with iron concretions	7	0
1. Gray to bluish heavy-bedded sandstone	1	6

The westerly dip of these varigated shales carries them below the level of the railroad about a mile and a half west of Caldwell, and the Mississippian ("Lower Carboniferous") limestone appears above them.

COVINGTON, ALLEGHANY COUNTY, VA.

The time spent at Covington was devoted mainly to collecting from the beds of the following section:

Section 1382 B, one-half mile southeast of the blast furnace on the north bank of Jackson River.

	Feet.
4. Black carbonaceous shale (Romney)	30
3. Greenish-gray shale	15
2. Coarse sandstone ("Oriskany")	3-6
1. Limestone (Lewistown)	15-25

The limestone cliff (1) on river bank, one-half mile below iron furnace, Covington, Va., contains the following species:

Faunule of zone 1 of section 1382 B, near Covington, Va.

[a, abundant; c, common; r, rare.]

1. Chætetes sp. (c).
2. Crinoid stem (r).
3. Lichenalia sp. (c).
4. Stropheodonta sp. (r).
5. Leptæna rhomboidalis (a).
6. Orthis sp. (r).
7. Rhipidomella oblata (c).
8. Gypidula pseudogaleata (r)·
9. Uncinulus mutabilis (c).
10. U. nobilis (r).
11. Eatonia peculiaris (c).
12. Rhynchonella sulciplicata (r).
13. Rensselæria æquiradiata (r).
14. Spirifer concinnus (a).
15. S. murchisoni (c).
16. Trematospira multistriata (r).
17. Meristella subquadrata (c).
18. Avicula sp. (r).
19. Platyceras robustum (r).
20. Platyostoma ventricosum (?) (r).

The coarse sandstone (2) contains the following species:

Faunule of zone 2 of section 1382 B, near Covington, Va.

[a, abundant; c, common.]

1. Dalmanella planiconvexa (r).
2. Rhipidomella musculosa (r).
3. R. cf. oblata (r).
4. Rensselæria ovoides (a).
5. Spirifer cf. arenosus (r).
6. Spirifer murchisoni (c).
7. Meristella lata (r).

The greenish shale (3) yielded the following forms:

Faunule of zone 3 of section 1382 B, near Covington, Va.

[c, common; r, rare].

1. Zaphrentis sp. (r).
2. Schizophoria cf. striatula (r).
3. Atrypa spinosa (r).
4. Ambocœlia umbonata (c).
5. Bellerophon sp. (r).
6. Pleurotomaria sp. (r).
7. Conularia sp. (r).
8. Phacops rana (c).

From the black shale (4), 25 to 30 feet above the Oriskany, the following species were collected:

Faunule of zone 4 of section 1382 B, near Covington, Va.

[a, abundant; c, common; r, rare.]

1. Strophalosia truncata (r).
2. Orthothetes chemungensis var. arctostriatus (c).
3. Leiorhynchus limitare (a).
4. Nucleospira cf. concinna (c).
5. Anoplotheca acutiplicata (c).
6. Buchiola speciosa (a).
7. Clinopistha cf. antiqua (r).
8. Nucula corbuliformis (c).
9. N. cf. lirata (r).
10. Nuculites triqueter (r).
11. Leptodesma sociale (r).
12. L. sp. (r).
13. Actinopteria sp. (r).
14. Pleurotomaria sp. (r).
15. Styliola fissurella (a).
16. Tentaculites gracilistriatus (a).
17. Coleolus tenuicinctus (c).
18. Hyolithes aclis (c).
19. Agoniatites vanuxemi (r).
20. Parodiceras discoideum (r).

The black shale (5), about 50 feet above the Oriskany, yielded the following forms:

Faunule of zone 5 of section 1382 B, near Covington, Va.

[a, abundant; c, common; r, rare.]

1. Orbiculoidea cf. lodiensis var. media (r).
2. Anoplotheca acutiplicata (c).
3. Panenka (?) sp. (r).
4. Styliola fissurella (a).
5. Tentaculites gracilistriatus (a).

About one-half mile north of Covington, at the side of the wagon road, just opposite the blast furnace (1382 A), the limestone (1) of the section given above is again well exposed to a thickness of about 65 feet. The following species were obtained:

Faunule of section 1382 A, near Covington, Va.

[a, abundant; c, common; r, rare.]

1. Lichenalia cf. torta (c).
2. Stropheodonta cf. beckii (c).
3. Orthothetes woolworthanus (r).
4. Uncinulus mutabilis (c).
5. Rensselæria æquiradiata (c).
6. Cyrtina rostrata (r).
7. Spirifer concinnus (a).
8. S. cf. cyclopterus (r).
9. Avicula cf. communis (r).
10. Diaphorostoma ventricosum (r).

West of Covington fossils were collected from the dark sandy shales which lie above the typical black shale at the following stations: 1382 C, west bank of Jackson River, one-fourth mile south of Chesapeake and Ohio Railway bridge at Covington, and 1382 D, hard, bluish-green shale, one-fourth mile west of Covington, on roadside. This is a somewhat higher horizon than 1382 C. The faunules obtained from these outcrops (Jennings) are as follows:

Faunule of section 1382 C, near Covington, Va.

[a, abundant; c, common; r, rare.]

1. Paracardium doris (a).
2. Coleolus sp. (c).
3. Hyolithes sp. (r).
4. Goniatites sp. (r).

Faunule of section 1382 D, near Covington, Va.

[c, common; r, rare.]

1. Paracardium doris (c).
2. Buchiola speciosa (c).
3. Nucula corbuliformis (c).
4. Palæoneilo sp. (r).
5. Pterochænia fragile (c).
6. Goniatites sp. (r).

HOT SPRINGS, BATH COUNTY, VA.

Hot Springs is about 25 miles north of Covington. Immediately northwest of the springs the Paleozoic beds, from the Devonian black shale to the Cambrian, have been tilted until they stand almost vertical. The "black shale" is not all black, some of the lower beds being a pure creamy white in color. A bed of very hard cherty sandstone, 50 or 60 feet in thickness, lies at the base of the black shale. This formation, which stands vertical here, resists weathering more effectively than those on either side, and resembles the ruins of a massive wall running up the side of the mountain.

All of the fossils collected at Hot Springs are from the beds above the sandy chert exposed along the railroad northwest of Hot Springs.

The section at Hot Springs northwest of the springs, along the Chesapeake and Ohio Railway, is as follows:

Section 1383 A, at Hot Springs, Va.

	Feet.
9. Dark greenish to drab-colored shale, just below section house, about 1¾ miles below Hot Springs	25
8. Dull bluish-gray shales	30
7. Tough sandy black shale, below automatic switch No. 1	60
Concealed	150
6. Ash-colored shale	10
5. Black and gray shales alternating	40
Concealed	60
4. Ash-colored shale	50
Concealed	60
3. White or cream-colored clay shale	9
2. Black shale (Romney)	10
1. Hard cherty sandstone ("Oriskany")	50–60

The following lists show the faunal associations disclosed in the several zones of this section (Romney-Jennings):

Faunule of zone 2 of section 1383 A, at Hot Springs, Va.

[a, abundant; c, common; r, rare.]

1. Orbiculoidea doria (c).
2. Chonetes cf. coronatus (r).
3. Anoplotheca cf. acutiplicata (a).
4. Styliola fissurella (c).

Faunule of zone 3 of section 1383 A, at Hot Springs, Va.

[a, abundant; c, common; r, rare.]

1. Crinoid stem (r).
2. Orbiculoidea doria (r).
3. Pholidops sp. (c).
4. Anoplia sp. (c).
5. Bellerophon leda (r).
6. Styliola fissurella (a).
7. Coleolus sp. (r).
8. Goniatites sp. (r).
9. Ostracods (c).

Faunule of zone 4 of section 1383 A, at Hot Springs, Va.

[a, abundant; c, common; r, rare.]

1. Orthothetes chemungensis var. arcto-striatus (a).
2. Chonetes cf. setigerus (r).
3. Leiorhynchus limitare (a).
4. Anoplotheca sp. (c).
5. Buchiola speciosa (a).
6. Actinopteria epsilon (r).
7. Styliola fissurella (a).
8. Tentaculites gracilistriatus (a).
9. Goniatites sp. (r).

Faunule of zone 5 of section 1383 A, at Hot Springs, Va.

[a, abundant; c, common; r, rare.]

1. Tropidoleptus carinatus (r).
2. Anoplotheca sp. (r).
3. Ambocœlia umbonata (a).
4. Actinopteria sp. (c).

Faunule of zone 6 of section 1383 A, at Hot Springs, Va.

[a, abundant; c, common; r, rare.]

1. Zaphrentis sp. (r).
2. Chonetes setigerus (r).
3. Leiorhynchus cf. laura (r).
4. Ambocœlia umbonata (r).
5. Buchiola speciosa (c).
6. Nucula lirata (c).
7. Pterochænia cf. fragile (large var.) (r).
8. Actinopteria epsilon (c).
9. Styliola fissurella (a).
10. Tentaculites gracilistriatus (a).
11. Coleolus tenuicinctus (r).
12. C. sp. (r).
13. Parodiceras discoideum (c).

Faunule of zone 7 of section 1383 A, at Hot Springs, Va.

[c, common; r, rare.]

1. Paracardium doris (c).
2. Pararca transversa (r).
3. Nucula sp. (r).
4. Orthoceras sp. (r).

Faunule of zone 8 of section 1383 A, at Hot Springs, Va.

[a, abundant; c, common; r, rare.]

1. Buchiola speciosa (c).
2. Palæoneilo constricta (r).
3. Pterochænia fragile (a).
4. Coleolus acicula (r).
5. Orthoceras sp. (r).

Faunule of zone 9 of section 1383 A, at Hot Springs, Va.

1. Pararca transversa (rare).
2. Panenka sp. (rare).
3. Pterochænia fragile (rare).

CLIFTON FORGE, ALLEGHANY COUNTY, VA.

The following section is exposed near the Chesapeake and Ohio Railway bridge just west of Clifton Forge:

Section 1384 A, near Clifton Forge, Va.

	Feet.
3. Ash-colored shale	125
2. Soft coarse brown sandstone ("Oriskany")	15
1. Hard blue limestone with chert bands in lower layers	80
Total	220

The coarse sandstone ("Oriskany") one-half mile west of Clifton Forge contains the following faunule:

Faunule of zone 2 of section 1384 A, one-half mile west of Clifton Forge, Va.

[a, abundant; c, common; r, rare.]

1. Stropheodonta sp. (r).
2. Leptæna rhomboidalis (r).
3. Rhipidomella cf. cumberlandiæ (r).
4. R. musculosa (r).
5. Eatonia peculiaris (r).
6. Rensselæria cumberlandiæ (r).
7. R. ovoides (a).
8. Cyrtina rostrata (r).
9. Spirifer cf. arenosus (r).
10. S. murchisoni (c).
11. Anoplotheca cf. flabellites (r).

No collecting was done in the beds above or below this sandstone.

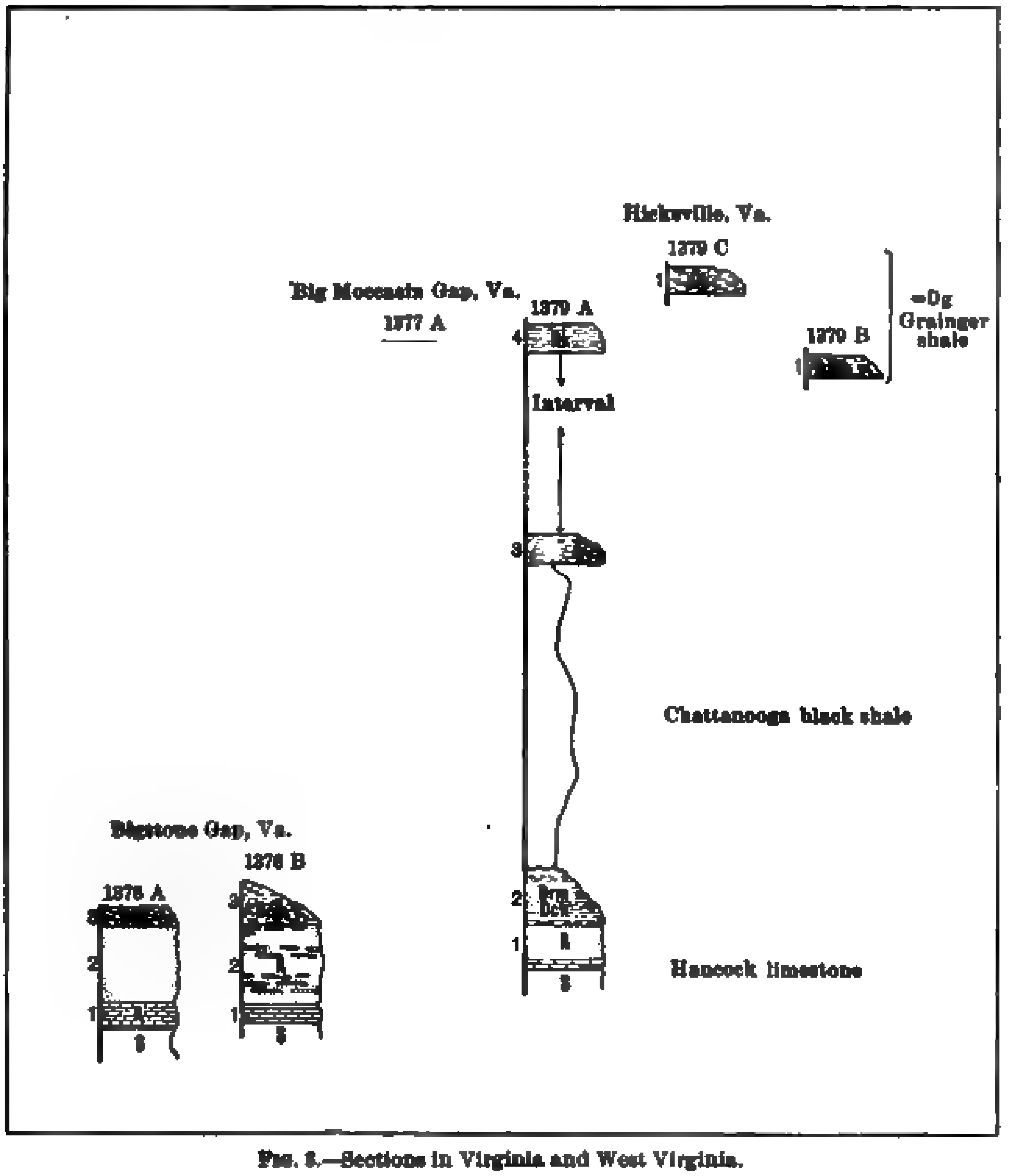


FIG. 8.—Sections in Virginia and West Virginia.

COMMENTS ON SECTIONS.

By H. S. Williams.

The facts here presented are chiefly valuable for the statistics themselves, viz, the detailed analysis of a number of local faunules. A word may be added, however, to indicate the bearing of these statistics upon the general problems of correlation, and upon the determination of the particular horizon to which each fauna should be assigned.

On the ordinary basis of correlation (i. e., the presence of species which have heretofore been recorded from some definite geological horizon) it is easy to indicate the general position of the several zones in the geological column. This general classification is indicated by the lettering of the separate parts of the sections which are arranged in approximately parallel order. (See sections, pp. 16, 28, 43.)

In this arrangement the capital letters O, S, R, D, and C are employed, with the following meaning: O indicates Ordovician; S indicates Silurian, not later than Niagara in age; R, the formation containing the Rensselæria fauna, called Giles formation in the Pocohontas folio, Hancock formation in the Estillville folio, the upper sandy portion of it being called Monterey sandstone on several of the Virginia and West Virginia sheets; D is used to indicate the Devonian formations as low as the Jeffersonville limestone of the Indiana survey; C indicates formations in which Carboniferous faunas are recognized.

On the east side of the Cincinnati arch there appears to be an unconformity at the base of the black shale. West of it (in Indiana, Tennessee, southern Illinois, and Arkansas) a limestone occasionally occurs conformably below the black shale. This limestone has a fauna which appears in the New York Onondaga limestone, and sometimes it contains traces of the *Tropidoleptus* fauna of the Hamilton formation of New York. Where this limestone occurs the unconformity appears below it.

There is considerable irregularity in the age of the formation immediately underlying the unconformity. In most of the western Kentucky and Indiana sections the underlying formation is Silurian and carries a Niagara fauna, but in some of the Kentucky sections, as well as in northern Arkansas, the highest formation below the unconformity is Ordovician. In the more eastern sections in Virginia and West Virginia the Rensselæria fauna is found in some of the uppermost Silurian formations immediately below the black shale. In western Tennessee, and also westward beyond Arkansas in Indian Territory,[a] traces of the Rensselæria fauna also appear.

It has not been definitely proved that there is an unconformity below the formation containing the Rensselæria fauna, but in both

[a] Girty, G. H., Preliminary report on Paleozoic invertebrate fossils from the region of the McAlester coal fields, Indian Territory: Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1899.

cases the faunal evidence suggests this interpretation. More evidence will be required before safe generalizations can be drawn as to the sequence of faunas in this part of the area.

CORRELATIONS.

By H. S. Williams.

The limestone and the terminal Silurian sandstone of the Estillville folio are undoubtedly the constituent parts of the "Hancock limestone" of that folio. The Hancock limestone is described as thinning out to the southeast, and in the correlation given by Campbell, it is the equivalent of the Meniscus limestone of Safford and of the Oriskany and Lower Helderberg of Stevenson.[a]

The Giles formation of the Pocohontas quadrangle is correlated with the Lower Helderberg and Oriskany by Mr. Campbell.[b] In northern and central Virginia the Lewistown limestone, including the chert lentil, is correlated with the Lower Helderberg, Salina, and Niagara, and the Monterey sandstone is correlated with the Oriskany.[c]

Mr. Darton describes the underground erosion of the Lewistown limestone as follows:

> The limestones are cavernous and many extensive caves have been discovered. One of them, the Blowing Cave, is in a small anticline traversed by Cowpasture River, 6 miles west of Panther Gap. * * * Springs, sinks, and other evidences of underground drainage are of general occurrence in the limestone area.

In this region the thickness of the Lewistown limestone varies from 550 to 1,080 feet, and that of the Monterey sandstone from 50 to 200 feet.

It will be noticed also that the black shale caps the series in all the sections described in all this part of the Appalachian province.

In Maryland the lower member is called Helderberg and varies from 750 to 900 feet in thickness, followed by black chert lentils. The next formation is the Oriskany, 325 to 350 feet thick, which is capped by the black shales of the Romney formation.[d]

These definitions are consistent with the following generalization: Upon a more or less pure limestone terrane of varying thickness (the Hancock, Lewistown, Helderberg) was deposited a cherty limestone which becomes sandy and ends in coarse sandstone, occasionally described as conglomerate; above these are the cherty lentils of the limestone (Giles formation or Monterey sandstone); above these is the base of the extensive Devonian black shale (Chattanooga, Romney).

In most cases there is more or less distinct evidence of underground solution of the limestone underlying the black shale. From a forma-

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[a] Geol. Atlas U. S., folio 12.
[b] Campbell, Geol. Atlas U. S.. folio 26.
[c] Darton, Geol. Atlas U. S., folio 61.
[d] Clark, W. B., Maryland Geol. Survey, Allegany County, 1900.

tional point of view the evidence favors the hypothesis that the waters which produced the erosion entered through the outcrops of the porous sandstone zone, and, percolating downward, took out the calcareous portion of the rocks unevenly, the sandstones settling as erosion proceeded; the amount of erosion being determined, partly at least, by the arenaceous admixture with the limestone. The irregular thickness was probably determined by the local position of the rocks relative to flowage of water through them.

In the more southern exposures erosion has been greater than in Maryland, northern Virginia, and West Virginia. The association of the iron ores with the sandstone portion of the formation may also be accounted for by the inwash of ferruginous waters into the cavernous interior from the surface, after the underground erosion had taken place. This interpretation is further borne out by the paleontological evidence.

THE RENSSELÆRIA FAUNA.

By H. S. WILLIAMS.

In the following table the species from each of the zones immediately underlying the black shale are tabulated. Twelve faunules are listed, and they are arranged approximately in their order from south to north. They are listed together on account of their evident faunal association, and because they are not separable on formational lines; that is, species which in the more northern sections are strictly associated with the calcareous and lower members of the series are, in the southern sections, included in the sandy beds. They may have been arenaceous beds which originally were calcareous sandstone, out of which the calcareous material has been leached by percolating waters after the edges of the beds were exposed to the surface drainage. The fauna is called in this paper the Rensselæria fauna, and includes species which have been referred to the Lower Helderberg and Oriskany formations as they were originally defined in the New York reports.

The Rensselæria fauna of the Appalachians.

[a, abundant; c, common; r, rare; L, Lower Helderberg; O, Oriskany.]

	Sections.												Range in New York formations.
	1876.					1879.		1880.	1882.		1884.		
	A1.	A2.	B2.	C.	E.	A1.	X.	A2.	B1.	B2.	A1.	A2.	
1. Zaphrentis sp	.....	r	r	.....	r	.....	.....	.....	.....	.....	.....	.....	....
2. Cyathophyllum sp	.....	.....	.....	.....	r	.....	.....	.....	.....	.....	.....	.....	....
3. Cystiphyllum sp	.....	.....	.....	.....	r	.....	.....	.....	.....	.....	.....	.....	....
4. Calceola cf. plicata	.....	.....	.....	r	.....	.....	.....	.....	.....	.....	.....	.....	....
5. Favosites sp	.....	r	.....	.....	r	.....	.....	.....	.....	.....	.....	.....	....
6. F. cf. Cladopora sp	.....	.....	.....	.....	r	.....	.....	.....	.....	.....	.....	.....	....
7. Aulopora sp	.....	.....	r	.....	.....	.....	.....	.....	.....	.....	.....	.....	....

The Rensselæria fauna of the Appalachians—Continued.

[a, abundant; c, common; r, rare; L, Lower Helderberg; O, Oriskany.]

	Sections.												Range in New York formations.
	1876.					1879.		1880.	1882.		1884.		
	A1.	A2.	B2.	C.	E.	A1.	X.	A2.	B1.	B2.	A1.	A2.	
8. Chætetes sp									c				
9. Aspidocrinus scutelliformis			r				a						L
10. Crinoid fragments								r	r				
11. Lichenalia cf. torta									c		c		L
12. Stictopora sp			r										
13. Polypora sp			r										
14. Fenestella sp					r								
15. Roemerella grandis			r										O
16. Pholidops cf. arenaria						c							O
17. Stropheodonta beckii	r		c								c		
18. S. lincklæni			r										O
19. S. magnifica			c										O
20. S. cf. planulata	r												L
21. S. sp						r			r			r	
22. Strophonella cavumbona	r	r	c										L
23. Leptæna rhomboidalis	c	c	a	r		r			a			r	
24. Orthothetes woolworthanus		r	c										L
25. Hipparionyx proximus								r					O
26. Chonetes sp. nov						r							
27. Anoplia nucleata						c							O
28. Orthis sp						r		c	r				
29. Dalmanella planiconvexa		r	r					c		r			
30. Rhipidomella cumberlandiæ												r	O
31. R. musculosa								a		r		r	O
32. R. oblata	r	c	a	r					c	r			L
33. Gypidula pseudogaleata	r		r	c	c				r				L
34. Amphigenia cf. elongata						r							
35. Rhynchotrema formosum			r										L
36. Camarotœchia ventricosa		a	a	c									L
37. Uncinulus campbellanus			r										L
38. U. mutabilis									c		c		L
39. U. nobilis									r				L
40. Eatonia peculiaris								c	c			r	
41. E. pumilla								c					O
42. Rhynchonella acutiplicata			c										L
43. R. altiplicata	c			r									L
44. R. oblata								r					O
45. R. sulciplicata									r				L
46. R. sp						r							
47. Rensselæria æquiradiata									r		c		L
48. R. cumberlandiæ												r	O
49. R. cf. marylandica								r					O

The Rensselæria fauna of the Appalachians—Continued.

[a, abundant; c, common; r, rare; L, Lower Helderberg; O, Oriskany.]

	Sections.												Range in New York formations.
	1876.					1879.		1880.	1882.		1884.		
	A1.	A2.	B2.	C.	E.	A1.	X.	A2.	B1.	B2.	A1.	A2.	
50. R. mutabilis	r		r										L
51. R. ovoides								a		a		a	O
52. R. sp			r										
53. Beachia cf. suessana								c					O
54. Atrypa reticularis			r		r								
55. Cyrtina dalmani	r	c	c										L
56. C. rostrata											r	r	O
57. Spirifer arenosus						c		a		r		r	O
58. S. concinnus									a		a		L
59. S. cumberlandiæ				c		a							O
60. S. cyclopterus		a	a				r						
61. S. murchisoni								c	c	c		c	O
62. S. (Delthyris) cf. perlamellosus					r								L
63. S. sp			r					r			r		
64. Reticularia fimbriata			r										O
65. Ambocœlia sp						r							
66. Trematospira multistriata									r				L
67. Nucleospira sp	r					r							
68. Anoplotheca cf. dichotoma						r							O
69. A. cf. flabellites								c				r	O
70. Meristella cf. bella			r										L
71. M. lata								r		r			O
72. M. lævis	c	c											
73. M. subquadrata	r		c	c	c				c				L
74. M. sp			r				r						
75. Avicula cf. communis			r						r		r		L
76. Cyrtolites (?) expansus					r								O
77. Loxonema sp			r										
78. Holopea antiqua			r										L
79. Platyceras cf. gebhardi					c			r					
80. P. robustum									r				L
81. P. pyramidatum		r											L
82. P. sp	r												
83. Diaphorostoma ventricosum						r		r	r		r		
84. Tentaculites elongatus	r	r				r							
85. T. sp					r								
86. Proetus protuberans		r											L
87. P. sp			r										
88. Homalonotus sp			r										
89. Phacops cf. cristata			r	r									O
90. P. logani			c										L
91. Dalmanites cf. anchiops				r	r								O
92. D. pleuroptyx				r									O

It will be observed by reference to the descriptive part of this paper that the zones 1376 A2, 1376 B2, 1379 A1, 1379 X, 1380 A2, 1382 B2, 1384 A2 are at present sandstone, often coarse-grained; the other zones are more or less calcareous.

The species which are peculiar to the Oriskany in New York are generally confined to the sandstone, but this is not always the case, nor are peculiar Helderbergian fossils restricted to the calcareous beds. In the New York sections *Aspidocrinus* appears in the "Shaly limestone" or "*Scutella* limestone" of the early reports, while in both sections in which it occurs in Virginia (Bigstone Gap 1376 B2 and Rocky Gap 1379 X) it is found in sandy beds. At Rocky Gap (1379 X) it occurs in a coarse sandstone similar to the typical Oriskany of New York.

It is evident that the subdivisions of the Rensselæria fauna, which in the northern Appalachian region have determined the division of the strata into numerous separate formations, are not universal. Future investigations probably will show that the composition of the local faunules is determined rather by environmental conditions recorded by the differing characters of the sediments than by actual epochs in their history.

THE BLACK SHALE AND ITS FAUNA.

By H. S. Williams.

It will be noted that while the New Albany shale reaches a thickness of 100 feet in Indiana, it thins out and is often not represented along the axis of the Cincinnati-Nashville arch. On the eastern side of this arch it thickens again eastward, and along the Appalachian channel is very thick. The "Chattanooga" shale attains a thickness of several hundred feet, and runs up into coarser and more irregular beds, known as the Grainger shale in southern, and as the Romney shale in northern, Virginia and West Virginia. The fauna of the pure black shale is very meager in both species and specimens.

At Louisville (1357 A3) the black shale contains *Lingula spatulata* and *Schizobolus concentricus*. Northeast of Brooks, Ky. (1365 A3), it holds *Leiorhynchus quadricostatum*, *Chonetes scitulus*, *Lingula spatulata*, and a small *Pleurotomaria*. In the Bigstone Gap region (1376 B3) it contains *Schizobolus concentricus* and *Lingula ligea*. In Bland County, Va., along Kimberling Creek (1379 A2), *Schizobolus truncatus* appears in rocks which are there classified as Romney shales, but which are only a few feet above the base of the Giles formation, which contains the Oriskany type of the Rensselæria fauna. The same species occurs in a similar black shale one-half mile north of Hicksville, Va., and is characteristic of the black shales of the White Sulphur Springs section (1380 A4).

If the list of species is taken as a whole it becomes evident that the fauna is the one represented in the Genesee shales of New York. This interpretation would appear to be confirmed by the faunule (1367 A) at Huber, Bullitt County, Ky., in which *Reticularia fimbriata*, *Athyris spiriferoides*, and *Tropidoleptus* occur in the limestone directly under the black shale. The reported range of the fauna as given in Schuchert's list of brachiopods is as follows:

Range of black shale species.

Lingula spatulata	Genesee-Portage.
L. ligea	Hamilton-Portage.
Schizobolus concentricus	Genesee.
Chonetes scitulus	Marcellus-Chemung.
Leiorhynchus quadricostatum	Genesee.
And a Pleurotomaria sp.	

The sequence of faunas at Hot Springs, Bath County, Va., presents another view of the case. There (1383 A) both *Anoplia* and *Anoplotheca* occur in the black shales, which are over 100 feet thick and lie below the zone (A5) which contains *Tropidoleptus carinatus;* and no species of either of those two genera is listed higher than the Onondaga (Corniferous) limestone. There is thus evidence that at Hot Springs the black shale sedimentation occurred as low as the Onondaga formation. Such a conclusion is confirmed by the presence in the faunule 1383 A4, of *Leiorhynchus limitare* and *Tentaculites gracilistriatus* (both regarded as confined to the Marcellus shale of New York) and *Anoplotheca.* This conclusion is also supported by the composition of the faunule of zone 1382 B4, a typical black shale within 30 feet of the top of the Rensselæria fauna, in which are found *Anoplotheca acutiplicata* (listed as an Onondaga (Corniferous) species) with *Leiorhynchus limitare* and *Agoniatites vanuxemi*, both listed as Marcellus species. Such facts indicate that the black shale was deposited in a thick mass in the Appalachian trough before the fauna of the Onondaga (Corniferous) formation was extinct.

As the sections are followed upward, the shales become coarse and flaggy and contain faunas which in New York occupy the formations from Onondaga upward to Chemung. The formations holding similar faunas in western Kentucky and Indiana, west of the Cincinnati arch, are calcareous at the base.

The fauna of the Sellarsburg beds contains traces at least of the fauna of the Hamilton formation of New York State, and thus furnishes reason for classifying the black shales of that region with the Genesee of New York.

THE BUCHIOLA SPECIOSA FAUNA.

By H. S. Williams.

Another argument for the belief that in the regions here discussed the black shales range from as low as the Onondaga to and beyond the base of the Carboniferous, is found in the distribution among them of forms which in New York State are listed as Nunda (Portage) species.

Take, for instance, the faunules containing *Buchiola speciosa.* They appear in black, shaly sediments and in the coarser shales following them in the middle Appalachian region. But a glance at the faunule lists shows that they belong to a general fauna which in New York is sometimes seen in one or other of the Marcellus, Genesee, and Nunda[a] formations, and only in insignificant proportions in any of the other formations, occupying the part of the column between the Marcellus to the Chemung.

For some of the species the range is lower or higher than these limits. From both the association in the faunules, and the absence of common genera of other formations of this part of the Devonian, it is fair to infer that *Buchiola speciosa*, *Pterochænia fragile*, *Paracardium doris*, *Parodiceras discoideum*, *Styliola fissurella*, *Tentaculites gracilistriatus*, and some other associated species, constitute a fauna which persisted for a considerable portion of middle Devonian time, represented in the New York sections by the formations from Marcellus to Nunda, inclusive.

The following table exhibits the association of the species of the *Buchiola speciosa* fauna in the Virginia faunules and their reported range in the formations of New York:

The Buchiola speciosa fauna represented in the Virginia sections and its reported range in the New York formations.

[a, abundant; c, common; r, rare; C, Chemung; G, Genesee; H, Hamilton; I, Ithaca; M, Marcellus; O, Onondaga; N, Nunda; W, Waverly.]

	Section.											Range in New York formations.
	1880.			1882.			1883.					
	B1.	D1.	E1.	B4.	C1.	D1.	A4.	A6.	A7.	A8.	A9.	
1. Orthothetes chemungensis var. arctostriatus	....	....	....	c	....	....	a	....	....	....	....	H.
2. Chonetes cf. setigerus	....	....	....	....	....	....	r	r	....	....	....	M, W.
3. Strophalosia truncata	....	....	....	r	....	....	....	....	....	....	....	H, N, I.
4. Leiorhynchus laura	....	....	....	....	....	....	....	r	....	....	....	M, H.
5. L. limitare	....	....	....	a	....	....	a	....	....	....	....	M.
6. Ambocœlia umbonata	....	....	....	....	....	....	....	r	....	....	....	M, C.
7. Nucleospira cf. concinna	....	....	....	c	....	....	....	....	....	....	....	O, H.
8. Anoplotheca acutiplicata	....	....	....	c	....	....	c	....	....	....	....	O.
9. Clinopistha cf. antiqua	....	....	....	r	....	....	....	....	....	....	....	O.
10. Paracardium doris	r	....	....	....	a	c	....	....	c	....	....	N.
11. Buchiola speciosa	a	a	a	a	....	c	a	c	....	c	....	H, G, N.

[a] See footnote on p. 86.

The Buchiola speciosa fauna represented in the Virginia sections and its reported range in the New York formations—Continued.

[a, abundant; c, common; r, rare; C, Chemung; G, Genesee; H, Hamilton; I, Ithaca; M, Marcellus; O, Onondaga; N, Nunda, W, Waverly.]

	Section.											Range in New York formations.
	1380.			1382.			1383.					
	B1.	D1.	E1.	B4.	C.	D.	A4.	A6.	A7.	A8.	A9.	
12. Pararca transversa									r		r	C.
13. Panenka sp			r								r	
14. Nucula corbuliformis				c		c						H, C.
15. N. cf. lirata				r				c				H.
16. Nuculites triqueter				r								M, H.
17. Palæoneilo brevis	r											[illegible]
18. P. constricta										r		H, N, C.
19. Leptodesma sociale				r								C.
20. Pterochænia fragile						c		r		c	r	M, H, G, N, C.
21. Actinopteria epsilon							r	c				C.
22. Plethospira socialis		a										
23. Styliola fissurella			a	a			a	a				M, G.
24. Tentaculites gracilistriatus				a			a	a				M.
25. Coleolus acicula							r					G.
26. C. tenuicinctus				c				r				H.
27. Hyolithes aclis				c								H.
28. Orthoceras bebryx var. cayuga	r											C.
29. Agoniatites vanuxemi				r								M.
30. Parodiceras discoideum	c			r	r	r		c				H.

The association of the several species of the Virginia faunules indicates the homeotopic relationship of the faunules, and leaves little room for doubt that no one of the species can be regarded as universally diagnostic of any particular zone of the middle Devonian, but for purposes of correlation indicates only some portion of the wide range of time expressed by the series of formations named.

THE FAUNULES, THEIR RANGE AND ENVIRONMENT.

By H. S. Williams.

An examination of the separate faunules brings out their relationship to each other, and also the relation between the faunal contents and the purity of the black-shale sediments.

In the lower part of these black shales of Virginia and West Virginia their normal fauna is present, as is shown in the faunules 1376 B3, 1379 A2, 1380 A4, 1382 B4 and B5, 1383 A2 and A3, which contain the following species:

Lingula ligea.	S. truncatus.
Schizobolus concentricus.	Chonetes scitulus.

These species occur in the southern sections, where the fine-grained black shale rests immediately upon the limestones. The shales are the typical Chattanooga shales.

The black shale at Hot Springs, Va., contains the following species:

Faunule of black shale of Hot Springs, Va.

1. Orbiculoidea doria.
2. Chonetes cf. coronatus.
3. Anoplotheca cf. acutiplicata.
4. Styliola fissurella.

This follows the hard cherty sandstones which stratigraphically represent the Oriskany.

The section at Covington presents 15 feet of gray shale between the top of the sandstone (Oriskany) and the black shale (1382 B4). The black shale (1382 B4 and B5) contains the following species:

Faunule of black shale at Covington, Va.

[a, abundant; c, common.]

1. Orbiculoidea lodiensis var. media.
2. Orthothetes chemungensis var. arctostriatus.
3. Leiorhynchus limitare (a).
4. Nucleospira concinna.
5. Anoplotheca acutiplicata (c).
6. Clinopistha antiqua.
7. Buchiola speciosa (a).
8. Nucula corbuliformis.
9. N. cf. lirata.
10. Nuculites triqueter.
11. Leptodesma sociale.
12. Actinopteria epsilon.
13. Styliola fissurella.
14. Tentaculites gracilistriatus.
15. Coleolus tenuicinctus.
16. Hyolithes aclis.
17. Agoniatites vanuxemi.

This fauna presents a combination of species not generally found in the New York formations, where the Marcellus, Genesee, and Nunda formations carry fairly distinct faunas. The dominant characteristics of the fauna are its Pteropods and *Buchiola speciosa*. Although it carries *Leiorhynchus limitare* in abundance, *Buchiola speciosa* is also abundant.

There are a few other zones holding evidently the same fauna, which lie higher up in the black shales of the more northern sections. I will select these on the basis of presence of *Buchiola speciosa*, either common or abundant. (See the chart, p. 5.)

1380 B1 adds the following species to the list above:

1. Paracardium doris.
2. Palæoneilo brevis.
3. Orthoceras bebryx var. cayuga.
4. Parodiceras discoideum.

1380 D1 adds *Plethospira socialis* and an unidentified *Loxonema*.

1380 E1 adds nothing.

1382 D1 adds *Pterochænia fragile* and *Goniatites*.

1383 A4 adds *Chonetes setigerus*.

1383 A6 adds the following species:

A small Zaphrentis.
Leiorhynchus cf. laura.
Ambocœlia umbonata.
Coleolus sp.
Parodiceras discoideum.

1383 A8 adds *Palæoneilo constricta* and *Coleolus acicula*.

None of these species are abnormal to the fauna. The association of species is characteristic of the Nunda formation[a] of New York, but there are a few species from a lower horizon.

In the Virginia section the fauna occupies the zone of coarse shales succeeding the pure, fine, smooth black shales, and from its stratigraphic position represents the fauna of the Nunda formation of New York. The rocks belong to the Romney and Jennings formations.

The sequence of sedimentation is regular, and there is a gradual change from pure, fine-grained black shale up to coarser and more arenaceous shale. These conditions are characteristic of the Grainger shales in which occur the *Buchiola speciosa* fauna.

Except for the greenish shale, 15 feet thick, of the Covington section, there is scarcely a trace of the faunas characteristic of the richly fossiliferous Onondaga (Corniferous) and Hamilton formations of New York, and it is evident from the fauna that follows that its horizon is not lower than the Nunda of New York. The greenish shale (1382 B3) underlying the black shale with this fauna in the Covington section contains a distinct fauna which is as follows:

Faunule of greenish shale at Covington, Va.

1. Schizophoria sp.
2. Atrypa spinosa.
3. Ambocœlia umbonata.
4. Phacops rana.

These species are indicative of a fauna ordinarily lower than the Nunda formation.[a] But the association of species alone, with the knowledge we now have of the range of the species of the Hamilton formation of New York, does not fix the age of this faunule with precision, since it is known to recur above the Ithaca fauna, and after species characteristic of the Chemung have appeared. Thus the faunal analysis indicates, not a regular succession of diverse faunas, but an interrupted succession of several faunas, each of which is recognized in the normal New York series, but the observed order of which does not strictly correspond with that characteristic of the standard New York sections.

It becomes necessary then to suppose interruption and replacement of faunas and a recurrence of early faunas at horizons above their (supposed) normal positions. This state of things has been elaborated in the study of the New York Devonian, but the detailed facts regarding these middle and southern Appalachian faunas is not sufficiently well known to make an exact correlation with the former possible at the present time.

[a] See footnote on p. 86.

THE UPPER DEVONIAN FAUNAS OF THE MIDDLE APPALACHIANS.

By H. S. WILLIAMS.

In order to exhibit the relation of the Upper Devonian faunas in this region to what goes before, it is sufficient to begin with the typical black shales and to consider in connection with them the faunules up to the first appearance of Carboniferous forms.

In the accompanying chart, representing the range of the species of the upper Devonian faunas for the Virginia and West Virginia region, the fauna of the black shale is tabulated in biological order with the species which follow it, so as to exhibit the changes in the bionic relations of the successive faunas and their replacement by new species of each of the genera which pass upward.

DISCUSSION OF THE CHART.

In the chart heavy lines separate the several continuous sections, which are represented by the numbers at the top. The local section is indicated by a capital letter; the particular zone of the section in which the faunule occurs is shown by the figure following the capital letter.

The bionic value of the species recorded for each faunule is indicated by the letters used in marking its presence, viz, r=rare, a=abundant, c=common, and o indicates that a representative of the genus occurs, the specific relation of which is indeterminate from the specimens in hand. The species are grouped so as to express their biological affinities, except under each genus the species are recorded in alphabetical order. The known range value of the species is indicated by the capital letters in the column at the extreme right. O=Onondaga, M=Marcellus, H=Hamilton, G=Genesee, N=Nunda,[a] I=Ithaca, C=Chemung, W=Waverly.

The chart shows the faunal combinations and vertical range of species, as far as they can be determined from the collections at hand. These data are still too imperfect to serve as a basis for a conclusive judgment concerning the local peculiarities of the range and distribution of the species, but they suggest points toward which future investigation may be directed.

In all the sections studied the fauna of the Hamilton formation of New York is conspicuous for its meagerness or total absence. In the more southern sections the fauna of the New York Chemung is likewise scant or absent.

Some, if not all, of the species from the Hamilton fauna recur above the Hamilton formation in the typical New York sections.

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[a] See footnote on p. 86.

Other Hamilton species appear as low as the Marcellus; and, as has already been stated, there is evidence of a common fauna tying together the Genesee and Marcellus, thus suggesting a separation of the typical *Tropidoleptus* fauna of the Hamilton from the *Buchiola speciosa* fauna already mentioned. The *Buchiola speciosa* fauna is seen in greater purity and with a fuller list of species in the southern sections, where the black shale sediments dominate the column for a greater vertical extent than at the north.

More facts are needed to fully differentiate these two faunas, but the dissections already made strongly suggest the probability that the faunas were contemporaneous over a great portion of their life history, and that the conditions of the sea bottom determined their geographical distribution as well as the particular zones in the stratigraphical column in which the one or the other appears.

The *Buchiola* fauna prevails wherever the Devonian black shale sedimentation was dominant, while the *Tropidoleptus* fauna exhibits its fullest development in the sediment composed of a fine-grained argillaceous mud, often more or less calcareous and typically rather light colored. A similar intercalation of two faunas is observed where the Trenton and Utica formations meet.

In the Virginia area under consideration the *Buchiola* fauna ranges above as well as below the *Spirifer disjunctus* zone. In New York *Spirifer disjunctus* is generally regarded as strictly indicative of the higher part of the upper Devonian, but it is not restricted to this horizon in Iowa, Nevada, and Arizona if the morphological affinity of *Spirifer whitneyi* and *S. disjunctus* is recognized, as is necessary when an attempt is made to correlate American with European faunas. Nevertheless the lower limit of the Chemung may be well distinguished in eastern North America by the first appearance there of *Spirifer disjunctus* and its normally associated fauna.

The significance, therefore, of the prevalence in the region under investigation of the *Buchiola* fauna up to the first appearance of *Spirifer disjunctus* is found in the inference that not only the *Tropidoleptus* fauna is there deficient, but that there is no distinct evidence of its immediate homeotopic successor, the fauna of the Ithaca member of New York.

LIST OF DIAGNOSTIC CHEMUNG SPECIES.

By H. S. Williams.

In the list below are given the species appearing in this southern extension of the fauna, which in New York are diagnostic of the Chemung formation and immediately follow the Nunda (Portage) formation:[a]

List of Chemung species.

1. Stropheodonta (Douvillina) mucronata.[b]
2. Strophonella cælata.
3. Productella hirsuta.
4. P. lachrymosa.
5. P. stigmata.
6. Dalmanella tioga.
7. Atrypa hystrix.
8. Spirifer disjunctus.
9. Delthyris mesicostalis.
10. Sphenotus contractus.
11. Edmondia, several species.
12. Macrodon chemungensis.
13. Leptodesma lichas, and several other species.
14. Mytilarca chemungensis.
15. Pterinea (Vertumnia) reversa.

The significant feature of the list is the absence of *Stropheodonta (Leptostrophia) interstrialis* Vanuxem, which is represented in the Ithaca faunas of New York; of *Spirifer pennatus* var. *posterus*, also an Ithaca species, and of the *Productella* which has generally been recorded as *P. speciosa*,[c] and was described from the Chemung of western New York. This form is, however, frequent in the Ithaca formation, and the characters which have served to distinguish it from the form coming later in the Chemung, i. e., *P. lachrymosa*, are as follows:[d]

> Umbo [is] much elevated above the hinge line, with the apex closely incurved, regularly arcuate from beak to base, and more rapidly curving to the sides; abruptly depressed on the sides of the umbo, and concave between it and the narrow, short ears.[c] * * * The species resembles some of the forms of *P. lachrymosa*, but the spiniferous tubercles are smaller, more closely arranged, and more numerous, while the umbo of the ventral valve is narrower and somewhat abruptly alternate.[e]

Figures 2, 4, 5, and 8 of Pl. XXV of the report above cited well express these features. The forms of the Chemung which have like surface markings are found to resemble more closely the figured specimens of *P. hirsuta*. Great variation is expressed in even a small collection of specimens from either horizon, and, while it is impossible to distinguish absolutely the earlier from the later forms, the characters above referred to are found in practice to be of considerable diagnostic value.

The range of *Dalmanella tioga* ("*Schizophoria tioga*") is given in Mr. Schuchert's list as "Portage and Chemung" (Dev.)."[f] After considerable study of the range values of the Devonian species, the writer

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[a] See footnote, p. 86.
[b] See note, p. 35.
[c] See Pal. N. Y., IV, 1867, p. 175, pl. 25, figs. 1-11.
[d] Ibid., page 175.
[e] Ibid., page 176.
[f] Bull. U. S. Geol. Survey No. 87, p. 375. See p. 36.

has come to the conclusion that this species does not occur in the New York sections until the Chemung fauna enters that province, thus marking the transition between the Nunda (Portage) formation[a] and the Chemung. This conclusion, which is founded on evidence furnished by numerous sections exhibiting continuous strata across the transition, causes the Erie shale of Leroy, Ohio, to be assigned to a horizon as high as the Chemung of New York, rather than in the Nunda (Portage). No trace of this species has been reported, so far as the writer is aware, from the Ithaca member or any equivalent horizon. Hence the species may be regarded as diagnostic of the Chemung formation, and not of the Nunda (Portage).

Delthyris mesicostalis is quoted by Schuchert as appearing in "Ithaca and Chemung (Dev.)."[b] If it be assumed that *Spirifer pennatus* Conrad var. *posterus*, H. & C.[c] and *Delthyris mesicostalis* Hall[d] are generically distinct they may be distinguished by the absence or very rudimentary condition of the median septum in the ventral valve of *Spirifer pennatus* var. *posterus* and its distinct development in *Delthyris mesicostalis*. If this is used as a distinguishing feature for specimens which are very similar in most other characters, it has been ascertained by the writer and those associated with him in Devonian studies that the specimens occurring at the horizon called the Ithaca member in central New York, and in all other regions where it is distinctly traced, belong to the form described as *Spirifer pennatus* var. *posterus*, and that specimens with a distinct septum do not appear in the sections until the incoming of the Chemung fauna above the Nunda (Portage) formation. Hence the species described as *Delthyris mesicostalis* Hall should be quoted as a diagnostic Chemung species, and as not occurring in the Ithaca member.[e]

[a] See footnote, p. 86.

[b] Bull. U. S. Geol. Survey No. 87, p. 207.

[c] Pal. New York, Vol. VIII, Pt. II, p. 361.

[d] Geol. New York, Rept. Fourth Dist., 1843, p. 269.

[e] See further notes on pp. 75, 76, 108.

CONTRIBUTIONS TO DEVONIAN PALEONTOLOGY, 1903.

PART II.

FOSSIL FAUNAS OF DEVONIAN SECTIONS IN CENTRAL AND NORTHERN PENNSYLVANIA.

BY

HENRY SHALER WILLIAMS and EDWARD M. KINDLE

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PART II.—FOSSIL FAUNAS OF DEVONIAN SECTIONS IN CENTRAL AND NORTHERN PENNSYLVANIA.

By H. S. Williams and E. M. Kindle.

PREFACE.

By H. S. Williams.

The sections discussed in the following pages were chosen for the purpose of extending the detailed knowledge of the faunas of the Devonian in a southeasterly direction across the beds from central New York, where the writer had already accumulated considerable evidence of their order and composition, to central Pennsylvania.

The facts already known suggested the probability that in Devonian time a shore line to the southeast limited the basin in which the sediments accumulated and the forms lived; they also led to the expectation that there would be a modification of the faunas to some degree, according to their distance from the shore line.

While the writer planned and directed the investigations, Doctor Kindle examined the sections and collected and identified the fossils. In the interpretation of the facts we have worked together and have reached the same conclusions. To the discussion, however, we have each contributed. The preparation of charts and faunal lists and method of treatment has been, in general, under the direction of the senior author, but the junior author has contributed many valuable suggestions and has done the most valuable part of the work—the gathering and elaboration of the facts themselves.

The following sections have been examined, and the order of succession and composition of the temporary faunules analyzed and reported for each:

The Catawissa section, East Bloomsburg, Columbia County, Pa., about 76° 30′ west longitude, and a little south of 41° north latitude.

The Hollowing Run section, lower Augusta Township, Northumberland County Pa., about at intersection of 76° 50′ and 40° 45′.

The Leroy section, composed of four shorter sections at Gulf Brook, near Leroy, Bradford County, Pa., Granville Center at South Mountain, the opposite side of the Towanda Creek from Leroy, and Towanda Narrows, about 6 miles east of Leroy. The general position of the section is near the intersection of 76° 45′ W. and 41° 45′ N.

The Tioga section, along Tioga River, near village of Tioga, Tioga County, Pa., near the intersection of 77° 10′ W. and 41° 50′ N.

The Mansfield ore bed section, about 8 miles south of Mansfield, Tioga County, Pa.

The Canoe Camp section, several miles still farther south on east side of Tioga River.

The Armenia Mountain section, two miles west of Troy, in Bradford County, Pa.

The last four sections belong together, though their actual continuity is not established by continuous sections. The system of recording and designating the faunules and their bionic values here adopted is the same as that employed and more elaborately defined in Bulletin United States Geological Survey, No. 210, "The Correlation of Geological Faunas."

INTRODUCTION.

By E. M. Kindle.

The two methods of correlation of stratified rocks which are in use are based upon the comparison and similarity of faunas and of rock sections. In their application one or the other of these methods is generally employed to the partial or entire neglect of the other. The paleontologist and the geologist have usually not the time or the inclination to make a minute study, respectively, of all the faunules or beds of a section. The two methods are supplementary, and neither can yield its best service in correlation when used independently of the other.

The ideal section from the standpoint of both correlation and faunal geology should show the thickness and character of the rocks and the lists of the species at each locality. The close relationship of the biological and the physical elements of the section are expressed in the accompanying sections. Both the paleontological and the stratigraphical data have been combined in the same section. The relation of the several elements of the faunas or the species to the section is indicated by the range and comparative abundance of each species.

The comparison of faunas can not give the most satisfactory results for purposes of correlation until the history of the faunas compared is fairly well known. Changing conditions of environment constantly

affect the distribution of the species of a fauna. The succession of advantageous and adverse conditions of life at a given locality leads to the frequent shifting of position of some of the individuals of a fauna, and sometimes to the migration of the entire fauna. The overlap of faunas, the change in the composition of faunas at different horizons, and the modification of species in ascending can be studied in a satisfactory manner only in connection with the rock sections in which these changes are recorded. It is believed that the present method of presenting paleontological and stratigraphical data in faunal cross sections will throw much light on such problems and be most effective in working out the life history of faunas.

The accompanying sections are intended primarily as a contribution to our knowledge of the geographical distribution and geological range of Devonian fossil faunas, and as an aid in the correlation of the upper Devonian formations of Pennsylvania and New York.

THE CATAWISSA SECTION, COLUMBIA COUNTY, PA.

DESCRIPTION OF SECTION.

By E. M. Kindle.

Susquehanna River cuts across the strike of the southward-dipping beds of the Montour anticline between the town of Catawissa and East Bloomsburg station, exposing in a continuous section the beds of the Devonian from the Hamilton formation up to the lowest "red beds." The work of the river in exposing the strata, which dip southward at an angle of 35° to 45°, has been supplemented by the construction of the Pennsylvania Railroad along its east bank, and the resulting section is probably not surpassed, if equaled, by any other in Pennsylvania in the opportunity which it affords for the study of upper Devonian faunas.

The lithological characteristics of the several beds are shown in the accompanying detailed section, which is followed by lists of the fossils obtained from each fossiliferous zone.

Section 1453 A, at Catawissa, Pa.[a]

			Ft.	in.
72.	(1)	Red shales, dip S. 10 E. 30°-35°	50	0
71.	(2)	Sandstone, greenish, massive, visible	10	0
70.	(3)	Concealed	110	0
69.	(4)	Greenish-gray sandstones, some shaly and also some reddish-brown sandstones	200	0
68.	(5)	Sandstone, gray, massive	10	0
67.	(6)	Red shale, sandy	100	0

[a] Numbers in parentheses refer to corresponding divisions of White's section, Second Pennsylvania Geol. Survey, Rept. G 7, p. 285.

	Ft.	In.
66. (7) Sandstone, green, flaggy	40	0
65. (8) Shales, red, sandy	30	0
64. (9) Sandstone, green	10	0
63. (10) Red shales, sandy	60	0
62. (11) Green sandstone	15	0
61. (12) Red shales	55	0
60. (13) Greenish sandstone	10	0
59. (14) Sandstone, green, current-bedded	10	0
57. (16) Red shales	90	0
56. (17) Sandstone, greenish-gray, massive	25	0
55. (18) Concealed with red and green bands, occasionally seen	120	0
54. (19) Sandstone, massive, greenish-gray	15	0
53. (20) Red shales	175	0
52. (21) Sandstone, massive, greenish-gray	50	0
51. (22) Concealed	70	0
50. (23) Brecciated limestone with fish remains	5	0
49. (24) Olive shales, sandy at top	40	0
48. (25) Red shale	12	0
47. (26) Concealed mostly, dip 35° to 40° S. 10° E	550	0
46. (27) Olive shales	175	0
45. (28) Concealed	275	0
44. (29) Olive shales	90	0
43[a] (30) Red shales	10	0
42. (31–34, 35? & 36?) Olive-gray shales and sandstone, mostly covered	225	0
41. (37) Sandy, olive-green shales	15	0
40. (37) Fossiliferous band	0	6
39. (37 in part) Hard, greenish-olive, sandy shale	30	0
38. Beds as above	4	0
37. Hard, olive-gray, sandy shale, with fossils common	60	0
36. Hard, olive-gray, sandy shale	30	0
35. Greenish-gray, fossiliferous shale	2	0
34. Hard, sandy, greenish-gray shales	75	0
33. Greenish-gray, sandy shale, fossiliferous at top	25	0
32. Hard, olive-gray, sandy beds	95	0
31. Olive-gray, sandy beds, with fossils	5	0
30. (41–44 in part) Olive-gray, hard, sandy beds, with occasional beds of crinoid stems	185	0
29. (45?) Hard, olive-gray, sandy beds, weathering to rusty brown	100	0
28. Bluish-gray, sandy beds, with two bands of large concretions	15	0
27. Dark bluish-gray, hard, sandy beds	63	6
26. Fossiliferous sandy beds	3	6
25. Bluish-gray sandy beds	18	0
24. Fossiliferous band	0	6
23. Bluish-gray, hard, sandy shale	20	0
22. Hard, bluish-gray sandy beds, with large concretions, fossiliferous at top.	18	3
21. Calcareous, fossiliferous bed	0	6
20. Hard, sandy, olive-gray beds, with large concretions near top	60	0
19. Bed of *Spirifer pennatus* var. *posterus*	0	3
18. Olive-gray sandy beds	35	0
17. Calcareous bed of fossils	1	0

[a] The section above 43 is given as published by I. C. White, Second Pennsylvania Geol. Survey, Rept. G 7, p. 285.

	Ft.	in.
16. Olive-gray sandy beds	25	0
15. (67?) Dark olive-gray sandy beds, with two highly fossiliferous bands	30	0
14. (68) Hard, dark bluish-olive sandy beds	70	0
13. (68 in part) Hard, dark bluish-olive sandy beds, fossils common	25	0
12. (69) Beds as above, nearly barren of fossils	91	0
11. (69) Beds as above, fossiliferous band at top	54	0
10. (69) Beds as above with fossiliferous band at top, apparently barren elsewhere	75	0
9. (69 in part) Hard, sandy, olive-gray beds, with 3 to 4 inch band of fossils at top	80	0
8. (70) Olive-gray sandy beds, breaking with splintery fracture	60	0
7. (71) Dark olive-brown sandy beds	20	0
6. (72) Olive-brown and bluish, hard, sandy beds (fossils near base)	175	0
5. (73) Dark blue, shaly, sandy beds	25	0
4. (74) Bluish-black fissile shale	225	0
3. (75) Hard, bluish-gray calcareous shale, weathering buff or ash-gray	25	0
2. (76 and 75 in part) Mostly covered	25	0
1. (76 upper part) Hard, sandy, dark bluish-drab shales	25	0

FAUNULES OF THE CATAWISSA SECTION.

By E. M. Kindle.

Zone 1 of Catawissa section (1453 A).—The lowest beds of the section outcrop in the bed and bank of the river at East Bloomsburg. They contain the following species:

Faunule of zone 1 of Catawissa section (1453 A).

[a, abunbant; c, common; r, rare.]

1. Pleurodictyum problematicum (r).
2. Stropheodonta (Douvillina) inæquistriata (r).
3. Pholidostrophia iowensis (r).
4. Chonetes coronatus (c).
5. Rhipidomella vanuxemi (c).
6. Leiorhynchus mesicostale (r).
7. Tropidoleptus carinatus (largest specimens nine-tenths of an inch wide) (a).
8. Spirifer granulosus (specimens large, and typical of the species) (a).
9. S. medialis (S. audaculus) (c).
10. S. pennatus (a).
11. Meristella cf. nasuta (r).
12. Palæoneilo emarginata (r).
13. P. plana (r).
14. Actinopteria decussata (r).
15. Aviculopecten sp. (r).
16. Modiomorpha cf. concentrica (r).
17. Cypricardella bellistriata (r).
18. Cyclonema hamiltoniæ (c).

The species composing this faunule are all characteristic Hamilton forms. This lowest zone of the section corresponds most closely, both in its fossils and lithology, with the typical Hamilton formation of New York State.

Zone 3 of Catawissa section (1453 A).—The beds of this zone, following those of zone 2 which are mostly covered, are well exposed along

the railroad on each side of the small ravine at East Bloomsburg, and contain the following faunule:

Faunule of zone 3 of Catawissa section (1453 A).

[a, abundant; c, common; r, rare.]

1. Zaphrentis cf. simplex (r).
2. Cystodictya cf. bifurcata (r).
4. Fenestella sp. (c).
4. Stropheodonta sp. (r).
5. Dalmanella tenuilineata (r).
6. Atrypa aspera (c).
7. Ambocœlia umbonata (a).
8. Platyceras sp. (r).
9. Styliola fissurella (a).
10. Tentaculites spiculus (c).
11. Phacops rana (c).
12. Dalmanites boothi (r).
13. D. cf. anchiops (r).

The rock containing these fossils contains only a small amount of lime and is perhaps equally well described either as a calcareous shale or as a very impure argillaceous limestone.

This bed has been called the Tully limestone by the Pennsylvania survey.[a] As it lies between typical Hamilton and Genesee beds, it unquestionably occupies the stratigraphical position of the Tully limestone of New York, but all of the fossils are Hamilton species, not one of the characteristic Tully forms appearing. This is doubtless to be explained by the fact that in physical characters this bed resembles the preceding Hamilton beds as much as or more than it resembles the Tully limestone of New York. The somewhat limey character of this bed indicates an approach toward the conditions of sedimentation prevailing in the typical Tully limestone area at the close of the Hamilton epoch, but the change from the Hamilton shale type of sediments was not sufficiently complete to induce the migration of the Tully fauna into the region, nor to drive out the Hamilton fauna, so that the latter continued to exist in a modified form. Although the fauna in this zone is a Hamilton fauna, the changed conditions of a later time interval are registered by the elimination of such characteristic Hamilton types as *Spirifer granulosus* and *Spirifer pennatus*, which were among the most abundant in the preceding zone.

While this zone does not contain the Tully fauna, the modified character of the Hamilton fauna which takes its place, together with its stratigraphical position between typical Genesee shales and Hamilton beds, justify the correlation of the Pennsylvania survey.

Prosser has shown that in eastern New York, where the Tully limestone is absent, its horizon is indicated at one locality by the presence of *Hypothyris cuboides* associated with *Spirifer pennatus*.[b] In the same region Clarke has shown that where the Tully and Genesee are absent "the Hamilton fauna has perpetuated itself without interruption."[c]

[a] Second Pennsylvania Geol. Survey Rept. G 7, pp. 282, 283, 287; Final Rept., vol. 2, p. 1319.
[b] Fifteenth Ann. Rept. State Geol., New York, p. 185.
[c] Thirteenth Ann. Rept. State Geol., New York, p. 554.

Zone 4 of Catawissa section (1453 A).—Careful search has failed to discover any fossils in the black shales of this zone. The physical appearance of the beds is identical with that of the Genesee shale, and no doubt a Genesee fauna will eventually be found in this region at this horizon.

Zone 5 of Catawissa section (1453 A).—The dark-bluish shaly beds, which form a transition from the fissile shales of zone 4 to the hard sandy beds of zone 6, appear, like the former zone, to be barren.

Zone 6 of Catawissa section (1453 A).—Near the base of 175 feet of hard, olive-brown, sandy beds the following faunule appears:

Faunule of zone 6 of Catawissa section (1453 A).

[c, common; r, rare.]

1. Plant remains (r).
2. Lingula sp. (r).
3. Chonetes lepidus (c).
4. Elymella fabialis (r).
5. Buchiola speciosa (r).
6. Nuculites cf. triqueter (r).
7. N. sp. (c).
8. Pterochænia fragile (c).
9. Lunulicardium curtum (r).

In this assemblage of species we have the first appearance of the *Buchiola speciosa* (Nunda) fauna in the section, suggesting the early stage of sedimentation of the Nunda (Portage) formation.[a]

Zone 7 of Catawissa section (1453 A).—This zone is the equivalent of No. 71 of White's section, and contains the following species:

Faunule of zone 7 of Catawissa section (1453 A).

[a, abundant; c, common; r, rare.]

1. Aulopora sp. (a).
2. Schizophoria striatula (r).
3. Cyrtina hamiltonensis (r).
4. Spirifer pennatus var. posterus (a).
5. Nucula bellistriata (r).
6. N. sp. (c).
7. Nuculites cf. triqueter (c).
8. Actinopteria sp. (c).
9. Leda diversa (c).
10. Pleurotomaria sp. nov. (c).
11. Macrochilina cf. hamiltoniæ (r).

The earliest appearance for this section of *Spirifer pennatus* var. *posterus* is in this faunule.

Zone 8 of Catawissa section (1453 A).—Fossils are scarce and difficult to collect at this horizon. The collection shows the following:

Faunule of zone 8 of Catawissa section (1453 A).

[c, common; r, rare.]

1. Crinoid stems (r).
2. Leiorhynchus mesicostale (c).
3. Nuculites sp. (r).
4. Palæoneilo emarginata (r).
5. P. sp. (r).
6. Leda sp. (r).

One or two individuals of *Leiorhynchus mesicostale* have the plications limited to four on the fold, and resemble *L. globuliforme.*

[a] See footnote, p. 86.

Zone 9 of Catawissa section (1453 A).—The faunule of this zone is from a 3- to 4-inch band of fossils, separated from the preceding zone by 80 feet of nearly barren beds. This zone contains the following species:

Faunule of zone 9 of Catawissa section (1453 A).

[a, abundant; c, common; r, rare.]

1. Cystodictya meeki (a).
2. Leiorhynchus mesicostale (c).
3. Spirifer pennatus var. posterus (c).
4. Palæoneilo emarginata (r).
5. P. cf. filosa (r).
6. Leda diversa (r).
7. Leiopteria cf. bigsbyi (r).
8. Actinopteria cf. perstrialis (c).

Three or four fragments of a small *Spirifer*, probably representing *Sp. pennatus* var. *posterus*, occur in this faunule.

Zone 10 of Catawissa section (1453 A).—At the top of 75 feet of barren beds, following zone 9, a thin fossiliferous zone bears the following faunule:

Faunule of zone 10 of Catawissa section (1453 A).

[a, abundant; c, common; r, rare.]

1. Crinoid stems (c).
2. Cyrtina hamiltonensis (a).
3. Spirifer pennatus var. posterus (c).
4. Nucula sp. (r).
5. Bellerophon sp. (c).
6. Cyclonema multilira (c). (The specimens are much larger than those figured by Hall, but agree with them in other respects.)
7. Orthoceras cf. fulgidum (r).

The association of the recurrent Hamilton forms, *Cyrtina hamiltonensis* and *Sp. pennatus* var. *posterus*, as dominant forms in this and other faunules of this section, is paralleled by the association of the same species in the Ithaca fauna of the Ithaca section. Above this zone, which is 435 feet above the Genesee shale of this section, *Sp. pennatus* var. *posterus* appears in most of the faunules up to the top of the section. This variety first appears as a common form in the Ithaca section 380 feet above the Genesee shale of that section, and is known by the writer to continue through at least 260 feet of the Ithaca beds.

Zone 11 of Catawissa section (1453 A).—Following the preceding zone are 54 feet of barren or nearly barren beds, at the top of which occurs the following faunule:

Faunule of zone 11 of Catawissa section (1453 A).

[a, abundant; c, common; r, rare.]

1. Cystodictya meeki (a).
2. Cyrtina hamiltonensis (r).
3. Spirifer pennatus var. posterus (r).
4. Reticularia lævis (r).
5. Sanguinolites (?) sp. (r).
6. Nucula sp. (r).
7. Palæoneilo plana (c).
8. Leda diversa (r).
9. Actinopteria perstrialis (a).

This faunule is of special interest because of the presence of *Reticularia lævis*, which hitherto has not been recognized outside of a limited area in central New York.

Zone 12 of Catawissa section (1453 A).—Ninety-one feet of nearly barren olive-gray sandy beds comprise this zone. No fossils were collected.

Zone 13 of Catawissa section (1453 A).—The 25 feet of dark bluish-olive sandy beds succeeding the last zone contain the following species:

Faunule of zone 13 of Catawissa section (1453 A).

[a, abundant; c, common; r, rare.]

1. Chonetes scitulus (a).
2. Productella cf. speciosa (r). (Two very small Productellas are doubtfully referred to this species.)
3. Camarotœchia eximia (a).
4. Leiorhynchus mesicostale (c).
5. Cyrtina hamiltonensis (c).
6. Spirifer mesistrialis.
7. S. pennatus var. posterus (a).
8. Nucula sp. (r).
9. Modiomorpha subalata var. chemungensis (?) (r). (A single small specimen referred to this species with some doubt).
10. Cypricardella gregaria (c).

Zone 14 of Catawissa section (1453 A).—Seventy feet of nearly barren sandy beds intervene between the last-mentioned and the succeeding fossiliferous zone. In this zone are found the following species:

Faunule of zone 14 of Catawissa section (1453 A).

[c, common; r, rare.]

1. Palæoneilo constricta (r).
2. P. plana (r).
3. Actinopteria perstrialis (c).
4. Loxonema cf. læviusculum (r).
5. Coleolus acicula (r).
6. Orthoceras cf. fulgidum (r).
7. O. sp. (r).

Zone 15 of Catawissa section (1453 A).—The fossils occurring in this zone are as follows:

Faunule of zone 15 of Catawissa section (1453 A).

[a, abundant; c, common; r, rare.]

1. Crania leoni (r).
2. Chonetes scitulus (r).
3. Productella speciosa (r).
4. Cryptonella eudora (a).
5. Tropidoleptus carinatus (r).
6. Atrypa reticularis (r).
7. Spirifer mesistrialis (a).
8. S. pennatus var. posterus (a).
9. Grammysia sp. (r).
10. Macrodon sp. (r).
11. Leptodesma sp. (r).
12. Actinopteria perstrialis (r).
13. Bellerophon sp. (r).
14. Pleurotomaria sp. (c).
15. Cyclonema sp. (r).
16. Platyceras sp. (r).
17. Tentaculites spiculus (c).

The above list contains many typical fossils of the Ithaca fauna. The presence of *Tropidoleptus carinatus* in this faunule is noteworthy

as representing a very late survival in this region of a typical Hamilton species.[a]

Zone 16 of Catawissa section (1453 A).—Succeeding zone 15 are 25 feet of nearly barren beds.

Zone 17 of Catawissa section (1453 A).—This zone is composed of a mass of fossil shells 1 foot in thickness at an elevation of 1,000 feet above the base of the section.

Faunule of zone 17 of Catawissa section (1453 A).

[a, abundant; c, common; r, rare.]

1. Cystodictya meeki (r).
2. Paleschara sp. (r).
3. Chonetes scitulus (a).
4. Cryptonella eudora (r).
5. Atrypa reticularis (r).
6. Cyrtina hamiltonensis (c).
7. Spirifer mesistrialis (a).
8. S. pennatus var. posterus (a).
9. Ambocœlia gregaria (r).
10. Actinopteria perstrialis (r).
11. Bellerophon sp. (r).
12. Cyclonema sp. (c).
13. Loxonema sp. (r).
14. Tentaculites spiculus (c).

Zones 18 to 20 of Catawissa section (1453 A).—The 35 feet of olive-gray beds (18) following the last zone are terminated above by a 3-inch band of the shells of *Sp. pennatus* var. *posterus* (19), above which comes 60 feet of hard sandy beds (20) with few fossils and with a bed of large concretions near the top.

Zone 21 of Catawissa section (1453 A).—A 6-inch band of calcareous rock contains the following faunule:

Faunule of zone 21 of Catawissa section (1453 A).

[a, abundant; c, common; r, rare.]

1. Zaphrentis sp.
2. Cystodictya meeki (c).
3. Cyrtina hamiltonensis (a).
4. Spirifer mesistrialis (a).
5. S. pennatus var. posterus (c).
6. Ambocœlia gregaria (r).

Zone 22 of Catawissa section (1453 A).—The species comprising the faunule of zone 22 are the following:

Faunule of zone 22 of Catawissa section (1453 A).

[a, abundant; c, common; r, rare.]

1. Stropheodonta (Leptostrophia) interstrialis[b] (r).
2. S. (L.) perplana var. nervosa (a).
3. Schizophoria striatula (r).
4. Cyrtina hamiltonensis (c).
5. Spirifer mesistrialis (c).
6. S. pennatus var. posterus (c).

Zone 23 of Catawissa section (1453 A).—Twenty feet of nearly barren beds follow the last horizon.

[a] With the exception of that species the faunule is very similar to one occurring in the middle part of the Ithaca member at Ithaca.—H. S. W.

[b] See footnote, p. 35.

Zone 24 of Catawissa section (1453 A).—A fossiliferous band 6 inches thick contains the following faunule:

Faunule of zone 24 of Catawissa section (1453 A).

[a, abundant; c, common; r, rare.]

1. Crania sp. (r).
2. Stropheodonta (Leptostrophia) interstrialis (c).
3. S. (L.) perplana var. nervosa (a).
4. Chonetes setigerus (r).
5. Schizophoria striatula (c).
6. Cyrtina hamiltonensis (c).
7. Spirifer pennatus var. posterus (a).
8. Glyptodesma erectum (r).
9. Pleurotomaria sp. (r).
10. Tentaculites spiculus (r).

Zone 25 of Catawissa section (1453 A).—This zone comprises 18 feet of bluish-gray sandy beds, sparingly fossiliferous.

Zone 26 of Catawissa section (1453 A).—Following the preceding zone are 3½ feet of beds, which hold the following faunule:

Faunule of zone 26 of Catawissa section (1453 A).

[a, abundant; c, common; r, rare.]

1. Cystodictya meeki (c).
2. Stropheodonta (Leptostrophia) interstrialis (r).
3. S. (L.) perplana var. nervosa (a).
4. Chonetes scitulus (c).
5. Productella speciosa (r).
6. Atrypa reticularis (a).
7. Cyrtina hamiltonensis (c).
8. Spirifer pennatus var. posterus (a).
9. Leiopteria cf. bigsbyi (r).
10. Actinopteria perstrialis (a).
11. Tentaculites spiculus (c).

The specimens here listed as *Sp. pennatus* var. *posterus* exhibit some interesting variations. Some of the specimens which represent the *posterus* type have the well-marked muscular impression in the ventral valve characteristic of this form, without any distinct trace of a median septum which characterizes the closely related form *Delthyris mesicostalis*. A few have the weakly developed median septum without the muscular impression, and represent an early stage of development of *Delthyris mesicostalis*. A majority of the specimens show both characters, the median septum being but slightly developed in any individuals.

Zone 27 to 30 of Catawissa section (1453 A).—Three hundred and sixty-three feet of nearly barren beds succeed the last zone.

Zone 31 of Catawissa section (1453 A).—Five feet of olive-gray sandy beds afford the following species:

Faunule of zone 31 of Catawissa section (1453 A).

[a, abundant; c, common; r, rare.]

1. Productella speciosa (r).
2. Schizophoria striatula (a).
3. Pugnax cf. pugnus (r).
4. Atrypa aspera (r).
5. A. reticularis (c).

The third species is represented by two small fragments doubtfully referred to this species.

Zone 32 of Catawissa section (1453 A).—Ninety-five feet of comparatively barren beds intervene between the preceding and the succeeding fossiliferous zones.

Zone 33 of Catawissa section (1453 A).—The following species are from the upper part of 25 feet of greenish-gray sandy shale:

Faunule of zone 33 of Catawissa section (1453 A).

[a, abundant; c, common; r, rare.]

1. Cystodictya meeki (r).
2. Chonetes scitulus (r).
3. Productella speciosa (a).
4. Pugnax pugnus (c).
5. Cyrtina hamiltonensis (r).
6. Spirifer pennatus var. posterus (a).
7. Reticularia lævis (r).
8. Sanguinolites sp. (r).
9. Nucula corbuliformis (c).
10. Palæoneilo filosa (c).
11. P. plana (r).
12. Actinopteria sp. (r).
13. Bellerophon mæra (r).
14. B. (Bucanopsis) leda var. (r).
15. Pleurotomaria sp. (r).
16. Loxonema sp. (r).
17. Orthoceras sp. (r).

This faunule is noteworthy as showing a second occurrence in the section of *Reticularia lævis* nearly 900 feet above its first appearance. In the Ithaca section it is known to have a vertical range of 520 feet. *P. pugnus*, which is here associated with *R. lævis*, is another form well known in the Nunda horizon of central New York.

Zone 34 of Catawissa section (1453 A).—Seventy-five feet of hard, sandy greenish-gray shales, carrying few fossils, follow the last zone.

Zone 35 of Catawissa section (1453 A).—Two feet of fossiliferous beds hold the following species:

Faunule of zone 35 of Catawissa section (1453 A).

[a, abundant; c, common; r, rare.]

1. Leiorhynchus mesicostale (a).
2. Pugnax pugnus (c).
3. Cyrtina hamiltonensis (a).
4. Spirifer pennatus var. posterus (a).
5. Grammysia sp. (r).
6. Nucula corbuliformis (r).
7. Palæoneilo filosa (r).
8. Actinopteria sp. (r).

The specimens of *Sp. pennatus* var. *posterus* in this zone have the greatly extended hinge line characteristic of those occurring at the Triphammer Falls horizon in the Ithaca section.

Zone 36 of Catawissa section (1453 A).—The beds of this zone hold the following faunule:

Faunule of zone 36 of Catawissa section (1453 A).

[a, abundant; c, common; r, rare.]

1. Craniella cf. hamiltoniæ (r).
2. Productella speciosa (c).
3. Schizophoria striatula (r).
4. Leiorhynchus mesicostale (a).
5. Pugnax pugnus (c).
6. Cyrtina hamiltonensis (c).
7. Spirifer pennatus var. posterus (a).
8. Palæoneilo plana (r).

The specimens of *Sp. pennatus* var. *posterus* are rather large, averaging about 1½ inches in width.

Zone 38 of Catawissa section (1453 A).—The following species occur in the 4 feet of beds included in this zone:

Faunule of zone 38 of Catawissa section (1453 A).

[a, abundant; c, common; r, rare.]

1. Stropheodonta cf. demissa (r).
2. Schizophoria striatula (c).
3. Leiorhynchus mesicostale (c).
4. Spirifer pennatus var. posterus (a).
5. Palæoneilo plana (r).
6. Pterinea chemungensis (r).
7. Ectenodesma birostratum (r).

Zone 39 of Catawissa section (1453 A).—Thirty feet of sparingly fossiliferous shales separate the last zone from the succeeding.

Zone 40 of Catawissa section (1453 A).—A 6-inch band of richly fossiliferous rock affords the following species:

Faunule of zone 40 of Catawissa section (1453 A).

[a, abundant; c, common; r, rare.]

1. Craniella cf. hamiltoniæ (r).
2. Stropheodonta cf. demissa (r).
3. Productella speciosa (c).
4. Schizophoria striatula (r).
5. Pugnax pugnus (a).
6. Atrypa aspera (r).
7. Cyrtina hamiltonensis (c).
8. Spirifer pennatus var. posterus (r).
9. Ambocœlia gregaria (r).
10. Nucula diffidens (c).
11. Palæoneilo cf. brevis (r).
12. Palæoneilo sp. (r).
13. Leptodesma sp. (r).
14. Mytilarca sp. (r).
15. Glyptodesma cf. erectum (r).
16. Ectenodesma cf. birostratum (r).
17. Goniophora cf. truncata (r).
18. Cypricardella cf. gregaria (r).
19. Bellerophon cf. mæra (r).
20. B. sp. (r).
21. Loxonema sp. (r).

It will be noted that nearly all of the species in this list occur in the Ithaca fauna. The third and fifth species (*P. speciosa*) and *P. pugnus*, which are the dominant forms of the faunule, are characteristic species of the Ithaca fauna. This is the latest faunule appearing in the section. No characteristic Chemung forms appear either in it or in any of the preceding faunules. It is to be observed also that this fauna ranges through approximately 1,400 feet. The pure Ithaca fauna at Ithaca occupies about 400 feet and the Chemung fauna begins less than 1,400 feet above the Genesee.

Zone 41–42 of Catawissa section (1453 A).—Olive-gray shales and sandstone, mostly covered and apparently barren, occupy the interval between the last zone and the lower "red bed."

Zone 43 of Catawissa section (1453 A).—This zone comprises 10 feet of red shales, is the lowest of the "red beds," and is barren of fossils. It is the highest bed in which careful search was made for fossils.

FORMATIONAL CORRELATION OF CATAWISSA SECTION.

By H. S. WILLIAMS.

The Catawissa section was chosen for special investigation because of its central position and because it has been adopted as a standard section in the interpretations of the geology of this and several adjacent counties. In Rept. G 7, I. C. White used it as a standard. The State geologist, J. P. Lesley, after consulting James Hall, of New York, concerning the points involved, allowed the paleontological facts to stand as reported. Criticism of the value of paleontology rather than of the correctness of the statements resulted from the confusion between the stratigraphy and the paleontology.[a]

The 10-foot bed of red shales (No. 89 of section, on p. 239 of Rept. G 7) was made the base of the Chemung-Catskill. On the north side of the river the same bed is recognized as No. 41 of the Rupert and Catawissa section.[b] I. C. White made the following statement:

> The reader will understand that the top of the Chemung has been fixed by me in the district at the base of the lowest red bed, and that all rocks below this, down to the top of the Hamilton, will be described under the name of Chemung, since I have found it impracticable to separate the Portage from the Chemung by any well-defined characters that will apply throughout the district, although it is very probable that 800′-1,000′ of the beds in the lower part of the group are the equivalent of the Portage beds in New York.
>
> The following section taken along the south bank of the Susquehanna River, beginning at the eastern end of the bridge across the latter stream at Rupert exhibits the distribution of the fossils in the Chemung.[c]

The identification of the fossils was upon the authority of Professor Claypole. In discussing the Catawissa section, I. C. White gives the following reasons for adopting this basis of classification:

> There comes at the bottom of the Catskill a series of rocks having such a mixture of Catskill and Chemung characters that it seems impossible to determine precisely the lower limits of the former, or the upper of the latter; and to bridge over the difficulty I have thought best to classify these transition beds as an intermediate Catskill-Chemung group.
>
> The base of the Catskill series, as limited in this report, has been placed at the horizon where the scales, teeth, and bones of *Holoptychius* make their first appearance.[d]
>
> Some geologists would doubtless cut off the Catskill at the base of No. 22 [of the Catawissa section] and place all the underlying portion of the section, 700′ thick, in the Chemung, because some shells of Chemung type occur in these beds; but since more than 1,000′ of red beds underlie the first bed, No. 54, at the bottom of the section, I prefer the conclusion that a few of the Chemung shells lived on, in this region at least, far into the Catskill period.[e]

[a] See Second Pennsylvania Geol. Survey, Rept. G 7, prefatory letter, sec. 24, p. xix; also p. 63, etc.
[b] Ibid., pp. 63-64. [c] Ibid., pp. 67-68. [d] Ibid., p. 54. [e] Ibid., p. 59.

The above quotations make it clear that I. C. White in 1883 accepted the first substantial red bed in the Devonian sections as the upper termination of the Chemung formation, and regarded the first fish bed with *Holoptychius* remains as the base of the true Catskill formation. For practical purposes (not fully approving it himself), he proposed to call the formations lying between these two zones the Chemung-Catskill.

In this section are to be found the evidences which have been taken for the classification of the upper Devonian formations of central Pennsylvania in general, as given in the Second Pennsylvania report.

A reference to the Prefatory Letter of Report G 7 will indicate the nature of the confusion introduced. In closing that letter the State geologist (J. P. Lesley) remarks:

> The startling fossil species of this report will therefore be regarded by the paleontologist . . . as only provisionally verified; while they must certainly stimulate American geologists to a closer study, and especially to a microscopic study, of several of our so-considered plainest and least ambiguous forms.[a]

In the following year, 1884, a sharp controversy arose in section E of the American Association for the Advancement of Science over the restatement of one phase of the same problem—the claim that *Spirifer mesistrialis* and *Spirifer disjunctus* were found together in the same formation. It was at that time my good fortune to know the statement to be correct, because I had a rock specimen containing both species. But none of the geologists knew at that time the real cause of the difficulty.

It was not known then that the first red bed could not be taken as the mark of the close of the Chemung formation, so long as Chemung was identified by marine fossils, and that the first fish beds did not occur uniformly at the same horizon in relation to the succession of marine faunas.

I believe very few geologists at that time were ready to accept the proposition that fossils which were known to represent separate stages of a continuous section in one region could actually occur together in the same zone of another section. The last remark of Professor Lesley's letter has proved correct. The fossils which were of critical importance were no doubt incorrectly labeled, and the conclusions which rested upon their identification were erroneous. This at least has been demonstrated by the recent study of the Catawissa section.

The diagnostic Chemung fossil *Spirifer disjunctus*, which was reported from three zones of the section below the first red bed and from four zones in the section on the north side of the river (the lowest of which is within 800 feet of the top of the Genesee), not only has not been found after special careful search of every foot of the

[a] Second Pennsylvania Geol. Survey, Rept. G 7, p. xxvi.

section, but the fossils that do occur represent faunas which are well known in New York State, none of which contain this species in any of their reported outcrops.

Since the lists of species have been officially reported, it is not sufficient to say that the species do not occur in the section. The statement that the classification, as it stands, is not in accordance with the paleontological facts, can not be accepted in place of the official reports without demonstrative evidence. It is not just to the geologists to charge them with wrong interpretation when they were relying on the accuracy of the paleontologist's determination. It has been thought fairer and better to neglect the statistics already reported, to examine the section anew, and to gather new series of fossils.

In order that the facts may be clearly before the reader, the interpretation of the section, as given by I. C. White in the report, will be briefly stated.

The lowest red bed of the section on the north side of the river is given as No. 41 of the section.[a] It outcrops at roadside near the mouth of a little run, 280 rods north from Catawissa station. It is given as No. 30 of the section on the north side of the river, and is there described as "Red shales, sandy, near east end of Rupert Bridge of Reading Railroad, this being the lowest red bed and base of transition."[b]

This was made the top of that part of the section specially examined by Doctor Kindle, and is No. 43 of his section. A reconnaissance survey of the higher beds did not show to him any marine invertebrate fossils, so that detailed search for fossils was not made. None are reported by I. C. White for this particular section above the first red bed No. 30.

On the north side of the river, marine fossils are reported above this red bed for nearly a thousand feet. The reported species are all Chemung.[c] These higher beds are classified as Chemung-Catskill.

The thickness of the section, according to I. C. White's estimate, is as follows:[d]

Thickness of beds of Catawissa section.

	Feet.
Chemung (strata Nos. 30-73, inclusive), and from the top of the Genesee to first red bed	2,300
Chemung-Catskill, or transition, to first fish bed	1,100
Catskill	1,412

The lower 1,000 feet, or thereabouts, was identified as equivalent to the Portage on basis of fossils.[e]

The thickness of the so-called Chemung, from the Genesee shales

[a] Second Pennsylvania Geol. Survey, Rept. G 7, p. 64.
[b] Ibid., p. 285.
[c] Ibid., p. 65.
[d] Ibid., p. 287.
[e] Ibid., p. 70.

to the base of the first red bed, Kindle estimated to be a little over 2,100 feet. No single section can be measured through the whole series, and the element of dip comes in to make up the difference in estimated thickness. Many of the zones of the original section were recognized by Kindle, but not all, and the section here reported upon is given on the basis of an independent examination and tabulation of the strata, the section, however, covers the same interval of rocks given in Rept. G 7.

The Stony Brook beds are identified in Rept. G 7 as No. 39 of the section. Whether I. C. White's identification of the beds in this section is correct or not, the Stony Brook beds were then regarded as of great value for determining horizons. I. C. White stated that the "Stony Brook horizon can be recognized anywhere within the region where-ever its beds are exposed, from Luzerne County to the southern part of Northumberland,"[a] and suggests that this zone may be present 50 or 150 feet below the third Venango oil sand in Crawford and Erie counties.

The four species which are said to be "always associated in the Stony Brook beds" are *Productella hirsuta*, *Spirifer disjunctus*, long-winged form, *Spirifer mesicostalis*, and *Leiorhynchus mesicostale.*[a]

The original outcrop of the Stony Brook beds is in Columbia County, at a cutting where the road crosses Stony Brook, one-half mile north of the south line of Orange Township. The brook empties into Fishing Creek.

On the evidence of the fossils, the following statement was made concerning the Stony Brook beds: "In fact this horizon seems to represent, par excellence, the typical Chemung rocks of New York in physical aspect as well as in fossils."[b] And in the final report, ten years later, this interpretation is confirmed.[c]

As is shown in the present report (see page 76) the fossils found in the rocks at the horizon called "Stony Creek beds" by I. C. White do *not* belong to the fauna of the typical Chemung formation of New York, but to a fauna always, in the New York section, found below the typical Chemung in what, along the Cayuga Lake meridian, is called the Ithaca member. In fact the combination of species is very close to that found in the central part of the typical Ithaca member of Ithaca, N. Y. Professor Hall's surmise, that the Stony Creek beds were middle Chemung, was nearer the truth, but in making that judgment he was misled by the report that *Spirifer disjunctus* was present in the fauna. Not a trace of that species has been found anywhere in the Catawissa section.[d] The use of this bed as evidence of the upper part of the typical Chemung, as in this and several other

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[a] Second Pennsylvania Geol. Survey, Rept. G 7, p. 72.
[b] Ibid., p. 92.
[c] Summary Final Rept. Second Pennsylvania Geol. Survey, vol. 2, p. 1564.
[d] See Second Pennsylvania Geol. Survey, Rept. G 7, p. xxx.

cases[a] is therefore misleading on account of misinterpretation of the fossils.

While this reliance upon wrong report of fossils has led to error, a mistake of another kind was made when I. C. White held that Chemung species occurred not only in his transition interval, called Chemung-Catskill, but also several hundred feet above the base of the Catskill.[b] This is accounted for by the supposed survival of Chemung species into the Catskill age. "But the marked absence of other well-known Chemung fossils shows that the above-mentioned species are merely five species which survived long beyond those with which they are associated in the genuine Chemung beds, into the Catskill age."[b] The same idea is conveyed in an earlier statement in which the author defends his determination of the base of the Catskill at the *Holoptychius* beds by saying: "Some geologists would doubtless cut off the Catskill at the base of No. 22, and place all of the underlying portion of the section, 700 feet thick, in the Chemung, because some shells of Chemung type occur in these beds; but since more than 1,000 feet of red beds underlie the fish bed, No. 54, at the bottom of the section, I prefer the conclusion that a few of the Chemung shells lived on, in this region at least, far into the Catskill period."[c] I quote this argument in full because it strikes at the very heart of the difficulty.

The first appearance of red beds and of *Holoptychius* in a stratigraphical section is there announced to be of more importance in determining the geological age of the beds than the presence of well-known representatives of a marine invertebrate fauna which is known to hold a definite place in the sequence of fossil faunas.

The problem may be expressed in simple terms, as follows: It is supposed that *Spirifer disjunctus* is characteristic of the Chemung fauna and red beds are typical of the Catskill formation. Where *Spirifer disjunctus* occurs in the midst of red beds I. C. White maintained that the rocks are of Catskill age and that *Spirifer disjunctus* lived on after its normal period (the Chemung). The opposite contention, which is here advocated, is that the age of the beds is Chemung and that the red beds were deposited earlier in this region than at places where they are found only above the *Spirifer disjunctus* zone of the section.

The issue was clearly recognized by me at the first reading of Report G 7, but it will be noticed at once that the question seems to be purely a matter of opinion, and there is no evidence to prove the correctness of either view. At the time of writing the report its author and the Pennsylvania survey were apparently in possession of the facts. The disregard of the interpretations by fossils was justified, since the species were incorrectly reported in a critical case. The problem could be solved only by such a perfect elaboration of the

[a] See Second Pennsylvania Geol. Survey, Rept. G 7, Pl. V., p. 66. [b] Ibid, p. 240. [c] Ibid, p. 59.

faunas that they would afford conclusive proof independent of red beds or any other purely physical characters. It has taken a long time to gather the evidence, but we are now able to prove by fossil evidence that the red beds, regarded as the top of the Chemung formation of this region by I. C. White, were deposited before the typical Chemung fauna occupied the seas of this region.

The evidence for this conclusion is found in the appearance of the Ithaca fauna immediately below the lowest red beds. This Ithaca fauna occupies the section down to within 200 feet of the black shale beds of the Genesee, where the typical Nunda fauna occurs. Below the Genesee a typical Hamilton fauna is seen. No characteristic Chemung fossils appear in the whole section at Catawissa. The successive appearance of the Hamilton, Genesee, lower Nunda, and Ithaca faunas, terminated above by red beds, demonstrates the important fact that the Catskill type of sedimentation began in this region before the Chemung epoch opened.

Professor Hall was right in stating that the beds were of Chemung age so long as they carried Chemung fossils (i. e., up to 22 of the I. C. White section). This would, however, carry the top of the Chemung formation 2,700 feet higher up than it is located in the report and would include all of I. C. White's Chemung-Catskill and 1,700 feet of his Catskill.

The present investigation has not gone far enough to positively confirm this conclusion, but the evidence afforded by the fossils of the Catawissa section that have been critically studied makes such a conclusion probable.

The facts published in the reports regarding the range of fossils in the sections are in favor of the interpretation given by Professor Hall. *Spirifer disjunctus* and other Chemung fossils were frequently reported above the base of the red beds. In the Fishing Creek section[a] fossils were reported 800 feet above the top of the so-called Chemung. In the Montour section[b] fossils were found 700 feet above the base of "Catskill" and 1,700 feet above the top of "Chemung." The Hartville section[c] (Luzerne County) shows Chemung fossils 150 feet above the base of the "Catskill."

It is evident from these reported cases that the fossils were of secondary importance in determining the upper limit of the Chemung. The first red beds, at whatever horizon they occurred, in relation to the fossils, were regarded as evidence of the top of the Chemung formation and the beginning of the Catskill series. The transition beds up to the first well-defined *Holoptychius* beds were called Chemung-Catskill.

That Professor Claypole, who identified the fossils, understood the confusion of evidence is clear from his report on Perry County. The

[a] Second Pennsylvania Geol. Survey, Rept. G 7, p. 215. [b] Ibid., p. 237. [c] Ibid., p. 196.

Kings Mill sandstone is placed in the Catskill formation, although he found in it, and in the overlying shales, fossils which he identified as typical Chemung species. The formation name was evidently applied because of the red shales and the *Holoptychius* beds, and he supposed that these beds were "passage beds between the Chemung and the Catskill, during the formation of which Catskill conditions more and more prevailed, rendering the seas less and less congenial to the Chemung fauna, until the latter became extinct; and then followed that vast accumulation of red sandstone and shale almost destitute of organic remains, except those of fishes, which is usually recognized as the Catskill formation."[a]

In conclusion it is to be noted that not a single species of the list of 15 diagnostic Chemung species mentioned on page 57 of this bulletin is found in the 2,000 feet of strata of this Catawissa section.

FAUNAL CORRELATIONS OF CATAWISSA SECTION.

By H. S. Williams.

Regarding the paleontological evidences presented in this section, the following comments may be made:

The first fossiliferous zone (1 to 3) contains the normal fauna of the Hamilton formation, as shown by the dominance of *Tropidoleptus carinatus*, *Chonetes coronatus*, *Rhipidomella vanuxemi*, *Spirifer pennatus*, *S. granulosus*, and *Phacops rana*, and the presence of *S. medialis*, *Palæoneilo emarginata*, *Modiomorpha concentrica*, *Cypricardella bellistriata*, and *Cyclonema hamiltoniæ*.

Zone 4 may be correlated, on account of its lithological similarity and in the absence of detected fossils, with the Genesee formation.

Zone 6 contains a fauna which is common in the Nunda (Portage) formation both above and below the horizon of the Ithaca fauna, and in sections in which the latter is absent. It is recognized by the presence and association of such species as *Buchiola speciosa*, *Pterochænia fragile* and *Lunulicardium curtum*. It contains *Chonetes* and *Lingula* but rarely species of any other genera of brachiopods.

The fossiliferous zone, extending from 7 to 26 inclusive, contains a fauna typical of the Ithaca member, as it is seen at Ithaca, N. Y. The diagnostic species are *Spirifer pennatus* var. *posterus*, *Sp. mesistrialis*, *Actinopteria perstrialis*, *Leiorhynchus mesicostale*, *Productella speciosa*, *Cystodictya meeki*, and *Stropheodonta* (*Leptostrophia*) *interstrialis*. The thickness here is 700 feet. At Ithaca, N. Y., the fossiliferous zone, which is characteristic, is not over 400 feet thick. *Reticularia lævis* appears in the Catawissa section 280 feet above the base of the fossiliferous zone. This first *Reticularia lævis* faunule occupies much the same position, in the sequence of development of the general

[a] Second Pennsylvania Geol. Survey, Rept. F 2, p. 76.

faunas, as in the Ithaca section. The fossiliferous zone extends about 400 feet above it in both cases; and the difference in the range of fossils, indicated by the statistics now on hand, is shown by the fact that in the Catawissa section such species as *Spirifer pennatus* var. *posterus*, *Schizophoria striatula*, and *Leiorhynchus mesicostale*, appear well below the first *Spirifer lævis* zone while in Ithaca they do not appear below it. It is noticeable that the brachiopods dominate above while in the lower 200 feet of the fossiliferous zone there are few brachiopods though there is a sparse fauna of gastropods, lamellibranchs and cephalopods. In this feature the Catawissa and Ithaca sections agree. This mingling of the two faunas, which are more sharply differentiated in the Ithaca section, is probably due to the geographical position of the section.

In western New York, along the Genesee Valley, the interval between the Genesee shale and the first appearance of the Chemung fauna is occupied by the Nunda formation, with no trace in it of the rich Ithaca fauna. Very little trace of that fauna is seen in the Seneca Lake Valley sections, while at Ithaca there is a zone of 400 feet preceded as well as followed by Nunda conditions and fauna. This zone is occupied by the rich brachiopod fauna of the typical Ithaca formation.

Points to be noted in the faunal combinations are the association of *Spirifer pennatus* var. *posterus* with *Reticularia lævis* in zone 11, and the appearance of the former over 200 feet lower in zone 7. Another interesting association is *Tropidoleptus carinatus*, in zone 15, with *Productella speciosa*, *Cryptonella eudora*, *Spirifer mesistrialis*, and *S. pennatus* var. *posterus*. This is evidently a recurrence from the Hamilton formation, and is to be correlated in time with the occurrence recorded in the Ithaca section in Bulletin 3 (page 15) of the faunule called in that report No. 14 N. The species *Tropidoleptus carinatus* does not appear in the latter zone at Ithaca so far as at present discovered, but several common Hamilton forms do.

From zone 26 upward for about 300 feet no fossils were detected, and the upper fossiliferous zone occupies the succeeding 400 feet. This upper zone (31–40) holds a fauna in which the dominant species are still those of the Ithaca beds. From 26 to 40, inclusive, may be correlated with the upper Nunda of the Ithaca section.

It will be noticed that the *Stropheodonta* is almost completely absent, a single species referred to, *S. demissa*, appearing in both 38 and 40. *Schizophoria striatula* is present, but *Cryptonella* is wanting, as is also *Spirifer mesistrialis*. *Pugnax pugnus* and *Reticularia lævis* are both present, the former frequently and in considerable numbers. *Productella hallana* is not recorded, but it probably would be found on more thorough search. These characteristics of the

upper fauna, associated with the absence of the Chemung species of *Productella*, *Orthis*, *Spirifer*, and *Delthyris*, indicate a continuation of the Ithaca fauna up through the zone, called upper Portage at Ithaca, where it was found to be nearly barren and represented only by recurrent Nunda (Portage) species.

This combination of species, seen in the upper part of the Catawissa section, is in harmony with the theory that the income of the western fauna was associated with the movements of the Nunda (Portage) sediments and fauna, while the Ithaca fauna was associated more intimately with the shiftings of the fauna of the Hamilton and is purer to the east, and is more restricted, both in species and in range, as it is followed westward across the States of Pennsylvania and New York.

Regarding the representatives of the western interior fauna, it may be said that, according to the present evidences, the *Reticularia* was the first to appear in this eastern area; then came *Pugnax* and *Productella hallana*, and at a still later incursion, *Strophonella* and *Spirifer disjunctus* were added.

It will be observed that species *Ectenodesma birostratum* and *Glyptodesma erectum* and two species of *Bellerophon* also appear in these upper faunules.

But, as Doctor Kindle has already noted, throughout this whole fossiliferous zone of the Catawissa section, up to the appearance of the characteristic red sediment of the Catskills, no characteristic Chemung species have been discovered. Using the Ithaca section as a standard, the Catawissa section, up to zone 40 (by the fossils), and presumably up to the base of the red bed 43, must be correlated with the Hamilton, Genesee, and Nunda (including the Ithaca member in the latter) formations.[a] Faunally the evidence of the Chemung formation must be looked for in the still higher strata.

THE HOLLOWING RUN SECTION, NORTHUMBERLAND COUNTY, PA.

DESCRIPTION.

By E. M. Kindle.

A second section was selected for detailed study on Susquehanna River, 25 miles southwest of the Catawissa section.

The Pennsylvania survey, in reporting upon this section, announced the occurrence in it of *Spirifer disjunctus* "in great numbers,"[b] and correlated all the beds above the "Genesee" as "Chemung." This particular section was subjected to investigation partly in order to test

[a] The name "Nunda formation," including the Ithaca member, has been adopted in the Watkins Glen folio (now in preparation) to designate what has heretofore been called the Portage, or Nunda, group. November, 1904. H. S. W.

[b] Second Pennsylvania Geol. Survey Rept., G 7, p. 358.

the correctness of this correlation. It was desired also to compare the vertical range of the species occurring in it with those of the Catawissa and other sections, to ascertain the variation of the faunas, and to learn whether any new faunal province appeared in that direction.

For 10 miles or more below Selinsgrove the Susquehanna River cuts across the folds of the Paleozoic rocks, approximately at right angles to the strike. A very good section is exposed on the east bank of the river, between the mouth of Hollowing Run and Selinsgrove Junction, extending down to the Salina. The beds dip to the south at from 35° to 45°. The strike is S. 70° W. magnetic.

Only the upper Devonian part of this section was studied by the writer. Beginning with the lowest beds studied, the section exposed along the railway is as follows:

Section 1454 A, at Hollowing Run, Pa.

	Ft.	in.
29. Tough olive sandy shale with few fossils	20	0
28. Tough olive sandy shale with fossils	10	0
27. Hard olive to grayish sandy beds, apparently barren	70	0
26. Hard olive-grayish sandy beds with fossils	10	0
25. Shaly dark olive sandy beds with occasional bands of crinoid stems and *Stictopora*	170	0
24. Olive-gray sandy shale	5	0
23. Dark olive sandy beds	65	0
22. Band of *Stictopora*	0	2
21. Dark olive sandy beds	100	0
20. Hard olive-gray sandy beds with fossils	10	0
19. Hard olive-gray sandy beds	90	0
18. Bed of closely crowded shells	0	4
17. Bluish-gray hard sandy beds, weathering brownish, with occasional fossils	125	0
16. Bluish-gray shaly sandy beds with lamellibranch fauna	5	0
15. Dark gray sandy shales	50	0
14. Dark gray shaly sandstone, weathering splintery	10	0
13. Dark bluish sandy shale and thin-bedded sandstone, apparently barren	200	0
12. Same as above, but containing a few fossils	20	0
11. Dark bluish somewhat sandy shale	30	0
10. Dark bluish-gray shales with some hard intercalated sandy beds	110	0
9. Covered 285 paces, estimated thickness	400	0
8. Bluish-gray shale	5	0
7. Covered	18	0
6. Dark fossiliferous shale	5	0
5. Dark somewhat sandy shale	220	0
4. Covered for 40 paces, estimated thickness	75	0
3. Dark sandy shales with ferruginous concretions	90	0
2. Dark sandy shales	15	0
1. Dark sandy shale and yellow sandstone	35	0
	1,963	6

FAUNULES OF THE HOLLOWING RUN SECTION.

By E. M. KINDLE.

Zones 1–8 of Hollowing Run section (1454 A).—The dark shales of the upper five of these zones contain *Spirifer pennatus*, *Tropidoleptus carinatus*, *Chonetes coronatus*, and other characteristic species of the Hamilton formation in abundance. The purpose of the present investigation being the study of the faunas above the Hamilton, to which these zones belong, detailed collections were not made from them.

Zone 9 of Hollowing Run section (1454 A).—This zone is concealed. The 400 feet which White estimated it to represent probably include the Genesee shales and some of the Hamilton beds.

Zone 10 of Hollowing Run section (1454 A).—The 110 feet of beds of this zone appear to be entirely barren. Their lithological characters, together with their position in the section, indicate that they belong to the Nunda (Portage) formation.

Zone 11 of Hollowing Run section (1454 A).—The 30 feet of shales of this zone hold the following faunule:

Faunule of zone 11 of Hollowing Run section (1454 A).

[a, abundant; c, common; r, rare.]

1. Cladochonus sp. (r).
2. Stropheodonta (Leptostrophia) interstrialis (a).
3. Buchiola speciosa (c).
4. Palæoneilo filosa (r).
5. Macrodon cf. hamiltoniæ (r).

This faunule, like the following, is distinctly Nunda in composition.

Zone 12 of Hollowing Run section (1454 A).—This zone contains the following faunule:

Faunule of zone 12 of Hollowing Run section (1454 A).

[c, common; r, rare.]

1. Aulopora sp. (c).
2. Reticularia lævis (r).
3. Leda diversa (r).
4. Coleolus acicula (r).
5. Orthoceras bebryx var. cayuga (r).
6. Goniatites sp. (r).

Reticularia lævis is represented by two well-preserved individuals. The beds containing this interesting species outcrop 22 paces above milepost 132.

Zone 13 of Hollowing Run section (1454 A).—The 200 feet following the last zone appears to be barren.

Zone 14 of Hollowing Run section (1454 A).—This zone contains the following species:

Faunule of zone 14 of Hollowing Run section (1454 A).

[a, abundant; r, rare.]

1. Cladochonus sp. (r).
2. Crinoid stems (r).
3. Schizophoria striatula (r).
4. Leiorhynchus mesicostale (a).
5. Grammysia sp. (r).
6. Nucula sp. (r).
7. Modiomorpha cf. neglecta (r).
8. M. subalata var. chemungensis (r).
9. Pleurotomaria capillaria (r).
10. Manticoceras sp.

Zone 15 of Hollowing Run section (1454 A).—No fossils were obtained from this zone, which appears to be nearly barren.

Zone 16 of Hollowing Run section (1454 A).—Five feet of shaly beds afford the following faunule:

Faunule of zone 16 of Hollowing Run section (1454 A).

[a, abundant; c, common; r, rare.]

1. Cladochonus sp. (r).
2. Crinoid stems (c).
3. Cystodictya meeki (c).
4. Stropheodonta (Leptostrophia) interstrialis (a).
5. Chonetes scitulus (c).
6. Productella hallana (r).
7. P. speciosa (c).
8. Pugnax pugnus (c).
9. Cryptonella cf. eudora (r).
10. Atrypa reticularis (c).
11. Cyrtina hamiltonensis (c).
12. Spirifer pennatus var. posterus (a).
13. Grammysia subarcuata (r).
14. G. sp. (r).
15. Spathella typica (r).
16. Nucula corbuliformis (r).
17. Palæoneilo plana (r).
18. Leda cf. obscura (r).
19. Mytilarca carinata (r).
20. Actinopteria epsilon (r).
21. Schizodus chemungensis var. quadrangularis (r).
22. Pterinopecten sp. (c).
23. Modiomorpha subalata (r).
24. M. subalata var. chemungensis (r).
25. Murchisonia sp. (r).
26. Platyceras cf. conicum (r). (One small individual is referred doubtfully to this species.)
27. Tentaculites spiculus (r).
28. Coleolus acicula (c).
29. Manticoceras complanatum (c).
10. M. sp.

This faunule displays very clearly the characteristics of the Ithaca fauna. All of the brachiopods occur in the Ithaca fauna, and most of the other species are known in it. The presence of *Productella hallana*, a rare species in eastern faunas, is noteworthy.

Zone 17 of Hollowing Run section (1454 A).—One hundred and twenty-five feet of sandy beds, containing very few fossils, succeed the last zone.

Zone 18 of Hollowing Run section (1454 A).—At the top of zone 17 are 4 inches of closely crowded shells, which contain the following species:

Faunule of zone 18 of Hollowing Run section (1454 A).

[a, abundant; c, common; r, rare.]

1. Stropheodonta (Leptostrophia) interstrialis (c).
2. Productella speciosa (c).
3. Schizophoria striatula (a).
4. Cryptonella eudora (r).
5. Atrypa reticularis (a).
6. Cyrtina hamiltonensis (a).
7. Spirifer pennatus var. posterus (a).
8. Nucula cf. corbuliformis (r).

be noted that *Pugnax pugnus* occurs repeatedly in this section, as it does in the Catawissa and Ithaca sections.

Zone 23 of Hollowing Run section (1454 A).—Above zone 22 are 65 feet of sandy beds, holding few fossils.

Zone 24 of Hollowing Run section (1454 A).—The following species are from 5 feet of olive-gray shales:

Faunule of zone 24 of Hollowing Run section (1454 A)

1. Stropheodonta (Leptostrophia) interstrialis, (common).
2. Schizophoria striatula (abundant).
3. Atrypa reticularis (common).

Zone 25 of Hollowing Run section (1454 A).—One hundred and seventy feet of dark olive sandy beds, barren, except for occasional bands of crinoid stems or *Cystodictya*, follow the last zone.

Zone 26 of Hollowing Run section (1454 A).—The 10 feet of beds comprising this zone afforded only a single species, *Schizophoria striatula* which is rare.

Zone 27 of Hollowing Run section (1454 A).—Sandy beds, 70 feet thick and apparently barren, follow the last zone.

Zone 28 of Hollowing Run section (1454 A).—Only two species, *Productella* cf. *speciosa* and *Atrypa* cf. *reticularis*, could be recognized in this zone. They are rare.

Zone 19 of Hollowing Run section (*1454 A*).—The 90 feet of beds above zone 18 contain few fossils.

Zone 20 of Hollowing Run section (*1454 A*).—The species comprising the faunule of this zone are the following:

Faunule of zone 20 of Hollowing Run section (*1454 A*).

[a, abundant; c, common; r, rare.]

1. Cystodictya meeki (a).
2. Stropheodonta (Leptostrophia) interstrialis (r).
3. Atrypa reticularis (c).
4. Spirifer pennatus var. posterus (a).
5. Spathella typica (r).
6. Palæoneilo plana (r).
7. Macrodon sp. nov. (r).
8. Pterinea cf. reproba (r.)

Zone 21 of Hollowing Run section (*1454 A*).—About 100 feet of dark-olive sandstone, having very few fossils, follow the last zone.

Zone 22 of Hollowing Run section (*1454 A*).—A 2-inch band, composed principally of a mass of *Cystodictya*, affords the following species:

Faunule of zone 22 of Hollowing Run section (*1454 A*).

[a, abundant; r, rare.]

1. Cystodictya meeki (a).
2. Crinoid stems (r).
3. Productella speciosa (r).
4. Pugnax pugnus (r).
5. Cyrtina hamiltonensis (r).
6. Palæoneilo sp. (r).

These species are all forms well known in the Ithaca fauna. It is to be noted that *Pugnax pugnus* occurs repeatedly in this section, as it does in the Catawissa and Ithaca sections.

Zone 23 of Hollowing Run section (*1454 A*).—Above zone 22 are 65 feet of sandy beds, holding few fossils.

Zone 24 of Hollowing Run section (*1454 A*).—The following species are from 5 feet of olive-gray shales:

Faunule of zone 24 of Hollowing Run section (*1454 A*)

1. Stropheodonta (Leptostrophia) interstrialis, (common).
2. Schizophoria striatula (abundant).
3. Atrypa reticularis (common).

Zone 25 of Hollowing Run section (*1454 A*).—One hundred and seventy feet of dark olive sandy beds, barren, except for occasional bands of crinoid stems or *Cystodictya*, follow the last zone.

Zone 26 of Hollowing Run section (*1454 A*).—The 10 feet of beds comprising this zone afforded only a single species, *Schizophoria striatula* which is rare.

Zone 27 of Hollowing Run section (*1454 A*).—Sandy beds, 70 feet thick and apparently barren, follow the last zone.

Zone 28 of Hollowing Run section (*1454 A*).—Only two species, *Productella* cf. *speciosa* and *Atrypa* cf. *reticularis*, could be recognized in this zone. They are rare.

common, r, rare.]

	Yellow sandstone and shale.	Dark s[...] ous [...]	Da[...]
COELENTERATA.			
Cladochonus sp			
Cystodictya meeki			
ECHINODERMATA.			
Crinoid stems			
MOLLUSCOIDEA.			
Stropheodonta (Leptostrophia) interstrialis			
Chonetes coronatus			
C. scitulus			
Productella hallana			
Productella speciosa			
Schizophoria striatula			
Leiorhynchus mesicostale			
Pugnax pugnus			
Cryptonella eudora			
Tropidoleptus carinatus			
Atrypa reticularis			
Cyrtina hamiltonensis			
Spirifer mesistrialis			
S. pennatus var. posterus			
S. pennatus			
Reticularia lævis			
MOLLUSCA.			
Spathella typica			
Grammysia subarcuata			
Grammysia sp			
Buchiola speciosa			
Palæoneilo filosa			
P. plana			
P. sp			
Leda diversa			
L. cf. obscura			
Nucula corbuliformis			
N. sp			
Macrodon hamiltoniæ			
M. sp. nov			
Pterinopecten sp			
Pterinea reproba ?			
Mytilarca carinata			
Actinopteria epsilon			
Schizodus chemungensis var. quadrangularis			
Modiomorpha subalata var. chemungensis			
M. cf. neglecta			
M. subalata			
Pleurotomaria capillaria			
Murchisonia sp			
Platyceras cf. conicum			
Tentaculites spiculus			
Coleolus acicula			
Orthoceras bebryx var. cayuga			
Manticoceras cf. complanatum			
M. sp			

Zone 29 of Hollowing Run section (1454 A).—Twenty feet of tough olive sandy shale, apparently barren of fossils, terminate the section.

Exposures cease before the "red beds" are reached. South of Hollowing Run no important outcrops appear until the axis of Little Mountain is passed, when the red Catskill beds, on the south side of the syncline, are seen dipping to the north.

FORMATIONAL CORRELATION OF HOLLOWING RUN SECTION.

By E. M. Kindle.

The bearing of the detailed paleontological data given in the preceding pages on the correlation of the section may be briefly summed up.

Zones 11 and 12 of the writer's section represent a portion of No. 8 of White's section, which he called the "Genesee shale." These beds have been found to hold a fauna which is distinctively Nunda. The physical characteristics of the beds, which are hard and slaty instead of fissile, confirm the evidence of the fossils and indicate that the lower beds of the section above the concealed interval (No. 9) should be referred to the Nunda formation.

The beds above the Genesee shale of White were referred by him to the Chemung.[a] The supposed discovery of *Spirifer disjunctus* in the section was apparently the reason for this correlation. A careful examination of every part of the section by the writer failed to discover any trace of that species. Since it was reported to occur in great numbers, it could hardly have been overlooked. The fauna which was secured at this horizon has such a distinctly Ithaca character that it is nearly certain that the determination of the form listed as *Sp. disjunctus* by White was an error. The presence of such species as *Sp. pennatus* var. *posterus*, *Productella speciosa*, and *Stropheodonta* (*Leptostrophia*) *interstrialis*, together with the absence of characteristic Chemung species, affords satisfactory and precise data for correlating with the Nunda (Portage) formation, including the Ithaca member, all of this section lying above the Genesee, which appears to belong in the concealed interval.

No very striking differences appear between this section and the Catawissa section. On the contrary, there are some interesting similarities. The comparatively rare forms *Reticularia laevis* and *Pugnax pugnus* are found in both sections. A few recurrent Hamilton species occur in each. *Cyrtina hamiltonensis* is common in both sections. No notable geographical changes in the faunas appear, both sections belonging to the same faunal province.

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[a] Second Pennsylvania Geol. Survey, Rept., G 7, p. 360.

COMMENTS ON THE PALEONTOLOGY OF THE HOLLOWING RUN SECTION.

By H. S. Williams.

The main fauna, ranging from zone 11 to 28 of this section, presents a general similarity to the fauna in the middle part (zones 10 to 33) of the Catawissa section. If the horizons in which *Reticularia lævis* first occurs be regarded as equivalent in the two sections, the 100-foot portion of the Catawissa section, including zones 21 to 26, is separated from the *Reticularia lævis* zone by something over 300 feet, the corresponding 100-foot portion of the Hollowing Run section contains a typical Ithaca fauna, and the central part of the typical fauna of the Ithaca member lies about the same distance above the conspicuous *Reticularia lævis* zone at the foot of Fall Creek section at Ithaca. It is to be noted that *Productella hallana* occurs with *Pugnax pugnus* in zone 16, as is the case in the typical Ithaca fauna of Ithaca.[a]

This upper fauna of the Hollowing Run section can be thus undoubtedly correlated with the fauna of the Ithaca member of the Nunda (Portage) formation. The association with it of such forms as *Cladochonus*, *Buchiola speciosa*, and *Goniatites* indicate the mingling of species of the typical Nunda sedimentation with the richer Ithaca fauna.

THE LEROY SECTION, BRADFORD COUNTY, PA.

Leroy is in Bradford County, Pa., about 22 miles south of the New York line. It is about midway between the previously described Catawissa section and Ithaca, N. Y., but lies a few miles to the west of a north-south line connecting these points. Four sections in the vicinity of Leroy, which together exhibit nearly all of the outcropping beds to the Pennsylvanian series, have been carefully measured, and taken together are called the Leroy section. These subsections, which will be described separately, are the Gulf Brook, Granville Center, Towanda Narrows, and South Mountain sections.

THE GULF BROOK SECTION.

By E. M. Kindle.

Gulf Brook enters the valley of Towanda Creek at Leroy, through a post-Glacial gorge which cuts directly across the strike of the Chemung rocks, exposing a section which the State geologist of Pennsylvania has called "the best section of the formation that we have in Pennsylvania."[a]

[a] Bull. U. S. Geol. Survey No. 3, pp. 18–19.

[b] Summary Final Rept. Second Pennsylvania Geol. Survey, vol. 2, p. 1448.

Mr. A. T. Lilley, of Leroy, published a description of the Gulf Brook section in 1886.[a] Lilley's section was republished by Lesley in 1892.[b] The writer is indebted to Mr. Lilley, who generously assisted in remeasuring and in collecting from the several zones of the section. Beds 63 to 66 of Lilley's section are omitted from the present section, since it is intended to include only those shown in the continuous section of Gulf Brook Gorge. The position of these beds with reference to the rest of the section, moreover, is problematical, since they outcrop in a horizontal position about 2 miles north of the Gulf Brook Gorge, near the axis of the Towanda anticline. The beds of the Leroy section dip to the south at angles varying from a maximum of 60° or more at the south end of the gorge to 5° or 6° at the north end, and expose the following strata:

Section 1455 A at Gulf Brook, Bradford County, Pa.

	Ft.	in.
99. Olive-gray sandy shale	90	0
98. Olive-gray flags	12	0
97. Olive-gray sandy shale	40	0
96. Calcareous gray sandstone	1	0
95. Brownish to olive, thin-bedded sandstone	6	0
94. Olive sandy shale and thin-bedded sandstone	20	0
93. Hard gray flagstone	8	0
92. Olive sandy shale	28	0
91. Reddish and gray sandy beds	10	0
90. Reddish sandy beds	14	0
89. Olive-gray shelly sandstone	12	0
88. Olive-green sandy shale	9	0
87. Gray limestone	0	4
86. Argillaceous green and reddish shale	7	0
85. Hard dark-red and mottled red and green bed	3	0
84. Soft argillaceous red shale	3	0
83. Covered	15	0
82. Hard red sandy beds	5	0
81. Dark-red ferruginous beds	3	6
80. Dark-red to greenish sandy beds	5	0
79. Dark-red low-grade iron ore	3	6
78. Dark-red to purple and gray sandy beds	9	0
77. Greenish shale and hard bluish-gray thin-bedded sandstone	20	0
76. Dark-colored shale with bands of iron ore	4	0
75. Reddish crinoidal limestone	3	0
74. Olive sandy shale	8	6
73. Reddish limestone	10	0
72. Olive-gray sandy shale with calcareous bands	17	0
71. Olive-green shaly sandstone, weathering brown, containing small chalcopyrite crystals	3	0
70. Hard bluish-gray to olive sandstone	20	0
69. Reddish to gray sandstone with limestone bands	4	0
68. Olive-gray shaly sandstone	20	0

[a] Proc. Am. Philos. Soc., vol. 23, pp. 291-293.
[b] Summary Final Rept. Second Pennsylvania Geol. Survey, vol. 2, pp. 1448-1450.

	Ft.	In.
67. Black ferruginous sandstone	5	0
66. Olive-gray sandy shale and shaly sandstone	9	0
65. Dark greenish-purple limestone	4	0
64. Greenish-gray shaly sandstone and shale	15	0
63. Cross-bedded purple limestone	5	0
62. Reddish-brown sandy beds with calcareous band near middle	4	6
61. Olive-gray thin-bedded sandstone, rough-bedded, with occasional dull-brownish beds (top of fall)	27	0
60. Dark-purple sandstone	2	0
59. Gray sandstone	2	0
58. Gray limestone with shell fragments abundant	1	0
57. Grayish-drab shaly sandstone	9	0
56. Dark-purple sandstone	2	0
55. Greenish sandstone	2	0
54. Reddish-brown sandstone with crinoid stems	1	0
53. Shaly olive-gray sandstone	9	0
52. Red highly ferruginous bed with crinoid stems and shell fragments	3	0
51. Dark brownish-purple sandstone with shell fragments and crinoid stems	8	0
50. Tough thin-bedded olive-gray sandstone	13	0
49. Tough thin-bedded olive-gray sandstone	10	0
48. Shaly sandstone and shale with occasional beds of hard sandstone	55	0
47. Tough thin-bedded sandstone and hard sandy shale	5	0
46. Dark-gray to olive-green sandy shale and shaly sandstone	100	0
45. Bluish drab sandy shale with two bands of shaly sandstone 10 inches thick, containing lowest *Spirifer disjunctus*	10	0
44. Grayish-drab sandy shale and shaly sandstone with large concretions near base	65	0
43. Hard sandy drab-colored shale	5	0
42. Shaly grayish-drab sandstone	70	0
41. Hard greenish thin-bedded, ripple-marked sandstone	35	0
40. Grayish-drab shaly sandstone	75	0
39. (Upper part) Drab thin-bedded sandstone and shale	15	0
38. Gray limestone composed of shell fragments	2	0
37. Bluish-drab sandstone and shale	50	0
36. Bluish-gray shale with hard sandstone layers at intervals	15	0
35. Olive-gray shale	6	0
34. Dark sandy shale and shaly sandstone	25	0
33. (Near middle) Dark-gray to bluish shaly sandstone and shale	60	0
32. Dark shale	4	0
31. Tough olive-colored sandstone	2	6
30. Thin-bedded gray sandstone	33	0
29. Dark bluish-gray shale	15	0
28. Bluish shaly sandstone with crinoid stems	4	0
27. Dark bluish-gray sandy shale with bands of sandstone	14	0
26. Grayish-brown fine-grained sandstone	1	8
25. Dark-grayish sandy shale	6	0
24. Bluish-gray limestone	0	6
23. Dark sandy shale and shaly sandstone	8	0
22. Bluish-gray shale and shaly sandstone	9	0
21. Bluish-gray sandy shale	12	0
20. Bluish-gray flags	10	0
19. Covered (to mouth of gorge)	10	0

	Ft.	in.
18. Dark-gray sandy shale and flags	14	0
17. Bluish-gray sandy shale	1	3
16. Hard bluish-gray sandstone	1	6
15. Dark bluish-gray shale	3	0
14. Dark bluish-gray sandy shale, partly covered	12	0
13. Bluish-gray hard sandy limestone	0	9
12. Olive-gray sandy shale	6	0
11. Covered (to forks of brook)	60	0
10. Soft olive-green shale nearly barren of fossils	20	0
9. Soft olive-green shale	3	0
8. Hard olive-green sandstone	0	6
7. Soft olive-green shale, interstratified with harder sandy beds	10	0
6. Soft olive-green sandy shale	5	0
5. Covered and sandstone	3	6
4. Hard flaggy dark-brown sandstone	0	6
3. Covered	4	0
2. Hard sandy olive shale	0	6
1. Soft olive-gray clay shale	1	6

The most important stratigraphical feature of the Gulf Brook section is the belt of limestone bands associated with purple shales and sandstones in the upper part of the section, comprising zones 58 to 75. This limestone belt is a constant feature over most of the western half of Bradford County, where it affords a most important key to the stratigraphy of the region. Sherwood applied the name Burlington limestone to its outcrops on the north side of the Towanda anticline near Burlington.[a] Since this name is preoccupied for a division of the Carboniferous of the Mississippi Valley, it is proposed to substitute the name Franklindale, because the beds are best exposed in the Gulf Brook section west of Franklindale.

Although the section shows no conglomerate horizon, a 6-foot bed of coarse conglomerate caps a hill about a mile west of the section. This conglomerate lies perhaps 300 feet below the Franklindale beds, which outcrop near it.

A band of conglomerate 8 or 10 inches thick outcrops one-third of a mile east of Gulf Brook, which lies a very little higher than the highest zone of that section.

In the road, 1½ miles west of Leroy, is an outcrop of a bed of iron ore which was supposed by Sherwood to be identical with a bed exposed near the top of the Gulf Brook section.[b] Claypole[c] has clearly shown that it lies, as Lilley first pointed out, at a considerably higher horizon, which he estimated at "perhaps 250 feet." The writer's measurements show a thickness of 284 feet of strata in the Gulf Brook section above the highest bed that approaches an ore in composition. The ore in question must therefore lie at Leroy some-

[a] Second Pennsylvania Geol. Survey, Rept. G 37.
[b] Ibid., p. 36.
[c] Proc. Am. Philos. Soc., vol. 20, 1883, p. 530.

where in the concealed interval which separates the Gulf Brook and South Mountain sections, probably 300 feet or more above the ferruginous zone No. 81 of the former section.

FAUNULES OF THE GULF BROOK SECTION.

Zone 1 of Gulf Brook section (1455 A).—The species found in the 18 inches of olive-gray clay shale comprising the lowest zone of this section are as follows:

Faunule of zone 1 of Gulf Brook section (1455 A).

[a, abundant; c, common; r, rare.]

1. Crinoid stems (r).
2. Chonetes lepidus (r).
3. C. setigerus (c).
4. Productella sp. (r).
5. Camarotœchia cf. eximia (r).
6. Ambocœlia gregaria (c).
7. Edmondia subovata (r).
8. Pholadella radiata (r).
9. Nucula corbuliformis (r).
10. Palæoneilo cf. bisulcata (r).
11. P. cf. elongata (r).
12. Leptodesma spinigerum (r).
13. Cypricardella gregaria (a).
14. Tentaculites bellulus (a).
15. Conularia congregata (r).

Of the 13 species which are specifically identified in this list, 8 have been recorded from the Ithaca fauna. Some of these, as 9 and 10, are recurrent Hamilton species.

Zone 2 of Gulf Brook section (1455 A).—The 6-inch zone following A1 contains the following species:

Faunule of zone 2 of Gulf Brook section (1455 A).

[c, common; r, rare.]

1. Chonetes lepidus (r).
2. Camarotœchia stephani (r).
3. Ambocœlia gregaria (a).
4. Leptodesma spinigerum (r).
5. L. sp. (r).
6. Leiopteria sp. (r).
7. Goniophora chemungensis (c).

Zone 3 of Gulf Brook section (1455 A).—This zone is concealed.

Zone 4 of Gulf Brook section (1455 A).—The 6 inches of sandstone of this zone holds the following fauna:

Faunule of zone 4 of Gulf Brook section (1455 A).

[a, abundant; c, common; r, rare.]

1. Chonetes lepidus (r).
2. C. setigerus (c).
3. Ambocœlia gregaria (r).
4. Nucula cf. bellistriata (r).
5. N. corbuliformis (c).
6. Palæoneilo bisulcata var. (c).
7. P. constricta (a).
8. P. perplana (c).
9. P. plana (a).
10. P. cf. tenuistriata (r).
11. Leptodesma spinigerum (c).
12. Schizodus sp. (r).
13. Goniophora chemungensis (r).
14. Cypricardella gregaria (c).

A. LOWEST LIMESTONE OF FRANKLINDALE BEDS

Part of Gulf Brook section, Pennsylvania

B. OSWAYO (POCONO) FORMATION.

Zone 12 of South Mountain section, Pennsylvania.

Zone 5 of Gulf Brook section (1455 A).—Three and a half inches of beds above zone 4 are concealed.

Zone 6 of Gulf Brook section (1455 A).—The 5 inches of soft olive shale of this zone afford the following species:

Faunule of zone 6 of Gulf Brook section (1455 A).

1. Lingula sp. (rare).
2. Pholadella radiata (rare).
3. Leptodesma spinigerum (abundant).

The first of these species is extremely abundant, practically excluding other forms. The three individuals of the third species are smaller than specimens figured by Hall. Radiating striæ are absent from one of them.

Zone 7 of Gulf Brook section (1455 A).—No fossils were collected from this zone.

Zone 8 of Gulf Brook section (1455 A).—This zone affords the following faunule:

Faunule of zone 8 of Gulf Brook section (1455 A).

[a, abundant; r, rare.]

1. Stropheodonta (Douvillina) mucronata (r).
2. Delthyris mesicostalis (r).
3. Ambocœlia gregaria (a).
4. Goniophora chemungensis (r).

Zone 9 of Gulf Brook section (1455 A).—The 3 inches of shale immediately following the last zone contain the following species:

1. Elymella sp. (rare).
2. Sphenotus solenoides (common).
3. Leptodesma spinigerum (rare).

Zones 10 to 12 of Gulf Brook section (1455 A).—No fossils were obtained from these three zones.

Zone 13 of Gulf Brook section (1455 A).—A 9-inch band of hard sandy limestone contains the following faunule:

Faunule of zone 13 of Gulf Brook section (1455 A).

[a, abundant; c, common; r, rare.]

1. Trematopora sp. (c).
2. Chonetes setigerus (c).
3. Delthyris mesicostalis (a).
4. Ambocœlia gregaria (a).
5. Leptodesma spinigerum (r).
6. Conularia sp. (r).

D. mesicostalis has a well-developed median septum in the ventral valve.

Zone 14 of Gulf Brook section (1455 A).—No fossils were collected from this zone.

Zone 15 of Gulf Brook section (1455 A).—This zone contains the following faunule:

Faunule of zone 15 of Gulf Brook section (1455 A).

[a, abundant; c, common; r, rare.]

1. Psilophyton sp. (r).
2. Dignomia alveata? (c).
3. Chonetes setigerus (c).
4. Ambocœlia gregaria (c).
5. Spathella typica (c).
6. Palæanatina cf. typa (r).
7. Leptodesma sp. (r).
8. Palæoneilo cf. emarginata (r).
9. Cypricardella cf. bellistriata (r).
10. C. tenuis (r).
11. Conularia cf. congregata (r).

Zones 16 to 19 of Gulf Brook section (1455 A).—Fossils are scarce in these zones. No collections were made.

Zone 20 of Gulf Brook section (1455 A).—Ten feet of flaggy sandstone afforded the three following species:

Faunule of zone 20 of Gulf Brook section (1455 A).

1. Productella arctirostrata (rare).
2. Ambocœlia gregaria (abundant).
3. Leptodesma sp. (rare).

Zone 21 of Gulf Brook section (1455 A).—This zone contains the following species:

Faunule of zone 21 of Gulf Brook section (1455 A).

1. Productella speciosa (rare).
2. Delthyris mesicostalis (common).
3. Ambocœlia gregaria (abundant).

The specimens of *D. mesicostalis* show a double fold on the brachial valve and a plication in the sinus.

Zone 22 of Gulf Brook section (1455 A).—The faunule of this zone includes the following forms:

Faunule of zone 22 of Gulf Brook section (1455 A).

1. Orthothetes cf. chemungensis (rare).
2. Productella speciosa (common).
3. Delthyris mesicostalis (common).

Zone 23 of Gulf Brook section (1455 A).—This zone afforded no fossils.

Zone 24 of Gulf Brook section (1455 A).—A 6-inch band of limestone contains the following faunule:

Faunule of zone 24 of Gulf Brook section (1455 A).

[a, abundant; c, common; r, rare.]

1. Orthothetes chemungensis (r).
2. Chonetes sp. (r).
3. Productella speciosa (r).
4. Dalmanella carinata (c).
5. Atrypa spinosa (r).
6. Spirifer mesistrialis.
7. Delthyris mesicostalis (c).
8. Ambocœlia gregaria (a).
9. Palæoneilo bisulcata (r).
10. Goniophora cf. chemungensis (r).
11. Orthoceras sp. (r).
12. Dinichthys cf. tuberculatus (c).
13. Onychodus sp. (r).

The occurrence in this zone of *Sp. mesistrialis*, associated with *D. mesicostalis*, is noteworthy since in normal sections the first form precedes the latter, the reverse of the order of their appearance in this section. The two forms have been very seldom found in association.

Zones 25 and 26 of Gulf Brook section (1455 A).—The 26 feet of beds comprising these zones are nearly barren of fossils.

Zone 27 of Gulf Brook section (1455 A).—This zone contains the following species:

Faunule of zone 27 of Gulf Brook section (1455 A).

[a, abundant; c, common; r, rare.]

1. Stropheodonta (Douvillina) mucronata (r).
2. Chonetes setigerus (a).
3. Spirifer mesistrialis (r).
4. Delthyris mesicostalis (r).
5. Ambocœlia gregaria (a).
6. Leptodesma cf. spinigerum (c).

Zone 28 of Gulf Brook section (1455 A).—Crinoid stems are the only fossils recognized in this zone.

Zone 29 of Gulf Brook section (1455 A).—Fossils are scarce at this horizon; the following species occur rarely:

Faunule of zone 29 of Gulf Brook section (1455 A).

1. Crinoid stems.
2. Chonetes setigerus.
3. Camarotœchia sp.
4. Palæoneilo sp.

Zones 30 to 32 of Gulf Brook section (1455 A).—These beds are nearly barren of fossil remains.

Zone 33 of Gulf Brook section (1455 A).—Fossils are scarce at this horizon, only three species being secured, namely:

Faunule of zone 33 of Gulf Brook section (1455 A).

1. Orthothetes chemungensis (rare).
2. Productella speciosa (common).
3. Delthyris mesicostalis (common).

Zone 34 of Gulf Brook section (1455 A).—Twenty-five feet of barren, thin-bedded sandstone follows the last zone.

Zone 35 of Gulf Brook section (1455 A).—Six feet of gray shale afford the following faunule:

Faunule of zone 35 of Gulf Brook section (1455 A).

[a, abundant; c, common; r, rare.]

1. Orthothetes chemungensis (a).
2. Chonetes setigerus (c).
3. Schizophoria striatula (c).
4. Spirifer cf. mesistrialis (r).
5. Delthyris mesicostalis (c).
6. Ambocœlia gregaria (c).
7. Palæoneilo sp.
8. Leptodesma spinigerum (c).

Zone 36 of Gulf Brook section (1455 A).—The following species characterize this zone, which is composed of 2 feet of impure limestone composed of shell fragments:

Faunule of zone 36 of Gulf Brook section (1455 A).

[a, abundant; c, common; r, rare.]

1. Stropheodonta (Leptostrophia) perplana var. nervosa (a).
2. Orthothetes chemungensis (r).
3. Productella speciosa (c).
4. Schizophoria striatula (r).
5. Spirifer mesistrialis (r).
6. Delthyris mesicostalis (c).
7. Orthonota parvula (r).
8. Spathella typica (r).
9. Edmondia cf. subovata (r).
10. Palæoneilo contracta (r).
11. Cypricardella gregaria (r).
12. Tentaculites cf. bellulus (r).

Zone 37 of Gulf Brook section (1455 A).—Fifty feet of barren sandstone beds succeed the last zone.

Zone 38 of Gulf Brook section (1455 A).—This zone contains the following faunule:

Faunule of zone 38 of Gulf Brook section (1455 A).

[a, abundant; r, rare.]

1. Orbiculoidea lodiensis var. media (r).
2. Camarotœchia stephani (a).
3. Sphenotus sp. (r).
4. Spathella sp. (r).
5. Nucula cf. varicosa (r).
6. Nucula sp. (r).
7. Palæoneilo sp. (r).
8. Leptodesma sp. (r).
9. Modiella pygmæa (r).
10. Modiomorpha subalata (r).

Zone 39 of Gulf Brook section (1455 A).—This zone holds the following meager faunule:

Faunule of zone 39 of Gulf Brook section (1455 A).

[a, abundant; c, common,]

1. Stropheodonta (Douvillina) mucronata (a).
2. S. (Leptostrophia) perplana var. nervosa (a).
3. Orthothetes chemungensis (c).
4. Spirifer mesistrialis (a).

Zones 40 to 42 of Gulf Brook section (1455 A).—These zones comprise 180 feet of nearly barren beds.

Zone 43 of Gulf Brook section (1455 A).—The following faunule occurs in 5 feet of sandy shale:

Faunule of zone 43 of Gulf Brook section (1455 A).

[a, abundant; c, common; r, rare.]

1. Crinoid joints (c).
2. Stropheodonta (Douvillina) mucronata (a).
3. Orthothetes chemungensis (c).
4. Camarotœchia cf. eximia (r).
5. Delthyris mesicostalis (r).
6. Cypricardella gregaria (r).

Mr. H. S. Williams makes the following statement concerning the occurrence of *Camarotœchia* cf. *eximia:*

There begins at zone 43 a fauna presenting some new features. The *Camarotœchia* is reported as *C.* cf. *eximia*. It resembles the form described by Hall as *Rhynchonella contracta* var. *saxatilis* which is said to present valuable characters connecting forms clearly referred to the New York species, *R. contracta*, and to young forms of *R. eximia*. The specimens in the Leroy Brook zone are small in size and resemble young forms of *R. eximia*, but some of the larger sized specimens may be referred to *R. contracta*. In the calcareous beds the smaller sized specimens are abundant. In the shale and ferruginous bands the form called *contracta*, with somewhat coarser and fewer plication and more abrupt and decided fold and sinus appears.

Zone 44 of Gulf Brook section (1455 A).—Sixty-five feet of barren beds follow the zone 43.

Zone 45 of Gulf Brook section (1455 A).—This zone contains the following species:

Faunule of zone 45 of Gulf Brook section (1455 A).

1. Camarotœchia cf. eximia (abundant).
2. Spirifer disjunctus (abundant).
3. Dipterus sp. (rare).

This faunule is interesting, because *Sp. disjunctus* makes its first appearance in the section at this horizon.

Zone 46 of Gulf Brook section (1455 A).—Zone 45 is followed by 100 feet of nearly barren beds.

Zone 47 of Gulf Brook section (1455 A).—Only one species, *Spirifer disjunctus*, was found at this horizon.

Zone 48 of Gulf Brook section (1455 A).—This zone is composed of 55 feet of barren sandy beds.

Zone 49 of Gulf Brook section (1455 A).—Resting on the preceding zone are 10 feet of thin-bedded sandstones containing the following species:

Faunule of zone 49 of Gulf Brook section (1455 A).

1. Camarotœchia cf. eximia (rare).
2. Spirifer disjunctus (rare).
3. Leptodesma sp. (rare).

Zones 50 to 59 of Gulf Brook section (1455 A).—These zones include the lowest "red beds" of the section, which are dull red to purplish rather than red. The fossils occuring in them are mostly fragmentary in character.

Zone 60 of Gulf Brook section (1455 A).—The 2 feet of dark purple sandstone of this zone contain *Camarotœchia* cf. *eximia* and *Spirifer disjunctus*. Both species are abundant.

Zone 61 of Gulf Brook section (1455 A).—Twenty-seven feet of thin-bedded sandstone with very few fossils extend from the last zone to the top of the first waterfall.

Zone 62 of Gulf Brook section (1455 A).—This zone, which lies at the top of the fall, contains *Camarotœchia* cf. *eximia* and *Spirifer disjunctus*. Both forms are common.

Zone 63 of Gulf Brook section (1455 A).—This zone includes 5 feet of cross-bedded purple limestone lying near the top of the fall. *Camarotœchia* cf. *eximia* is abundant and *Spirifer disjunctus* is common.

Zones 64 to 68 of Gulf Brook section (1455 A).—These zones contain comparatively few fossils.

Zone 69 of Gulf Brook section (1455 A).—Four feet of reddish limestone at the foot of the falls contain the following species:

Faunule of zone 69 of Gulf Brook section (1455 A).

[a, abundant; c, common; r, rare.]

1. Camarotœchia cf. eximia (a).
2. Cryptonella cf. eudora (a).
3. Spirifer disjunctus (c).
4. Modiomorpha sp. (r).

The *Cryptonella eudora* noted here is a much larger variety than that occurring in the Ithaca fauna; otherwise the two appear to be identical.

Zones 70 to 72 of Gulf Brook section (1455 A).—No collections were made from these zones. Fossils are scarce in them.

Zone 73 of Gulf Brook section (1455 A).—Ten feet of reddish limestone near the lower end of the gorge contain the following fossils:

Faunule of zone 73 of Gulf Brook section (1455 A).

1. Fistulipora sp. (rare).
2. Camarotœchia cf. eximia (common).
3. Cryptonella eudora var. (rare).
4. Spirifer disjunctus (abundant).

The specimens of *Sp. disjunctus* are large, squarish, slightly convex shells with a wide, shallow sinus and slightly elevated fold.

Zones 74 to 77 of Gulf Brook section (1455 A).—These zones, which aggregate a thickness of 35 feet 6 inches, outcrop in a field a few rods east of the gorge. They contain at this point an abundant fish fauna, embracing the following species:

Faunule of zones 74 to 77 of Gulf Brook section (1455 A).

1. Holonema rugosa.
2. Bothriolepis minor.
3. Holoptychius filosus.
4. Coccosteus macromus.

The fishes listed from this zone were collected by Mr. A. T. Lilley and identified and described by Cope.[a] The fish remains are most

[a] On some new and little known Paleozoic vertebrates: Proc. Am. Philos. Soc., vol. 30, 1892, pp. 221-228.

easily secured from the outcrop of the limestone in a field a few rods east of the brook.

Zone 78 of Gulf Brook section (1455 A).—Above the fish beds are 9 feet of purplish beds, from which no fossils were secured.

Zone 79 of Gulf Brook section (1455 A).—An arenaceous impure iron ore contains the following faunule:

Faunule of zone 79 of Gulf Brook section (1455 A).

[a, abundant; r, rare.]

1. Orthothetes chemungensis (r).
2. Camarotœchia cf. eximia (a).
3. Cryptonella cf. eudora (a).
4. Spirifer disjunctus (a).

The *Cryptonellas* are of very large size, as in the preceding zones.

Zones 80 to 86 of Gulf Brook section (1455 A).—These zones contain very few fossils.

Zone 87 of Gulf Brook section (1455 A).—Four inches of gray limestone hold the following faunule:

Faunule of zone 87 of Gulf Brook section (1455 A).

[a, abundant; c, common; r, rare.]

1. Orthothetes chemungensis (c).
2. Camarotœchia cf. eximia (r).
3. Cryptonella eudora var. (a).
4. Spirifer disjunctus (a).

The shells of No. 4 have a high area, deep sinus, and prominent fold, the general contour of the shell presenting a strong contrast to the type of shell occurring in zone 73. The shells of *O. chemungensis* are all small, none exceeding one-half inch in length.

Zone 88 of Gulf Brook section (1455 A).—Nine feet of barren shale follow the last zone.

Zone 89 of Gulf Brook section (1455 A).—This zone contains the following faunule:

Faunule of zone 89 of Gulf Brook section (1455 A).

[a, abundant; c, common; r, rare.]

1. Stropheodonta (Douvillina) mucronata (r).
2. S. (Leptostrophia) perplana var. nervosa (r).
3. Orthothetes chemungensis (c).
4. Schizophoria striatula (c).
5. Camarotœchia cf. eximia (c).
6. Atrypa spinosa (a).
7. Spirifer disjunctus (r).
8. Sphenotus sp. (r).
9. Dipterus (Ctenodus) cf. flabelliformis (r).

Zones 90 to 95 of Gulf Brook section (1455 A).—These zones contain few fossils. No collections were made from them.

Zone 96 of Gulf Brook section (1455 A).—This zone, comprising 1 foot of fossiliferous sandstone, contains the following faunule:

Faunule of zone 96 of Gulf Brook section (1455 A).

[a, abundant; c, common; r, rare.]

1. Aulopora sp. (r).
2. Orthothetes chemungensis (a).
3. Atrypa spinosa (r).
4. Spirifer disjunctus (c).
5. Leptodesma sp. (r).

This is the highest fossiliferous zone of the section. The beds following it, which extend to the lower end of the gorge, appear to be entirely barren.

GRANVILLE CENTER SECTION.

By H. S. Williams.

One-half mile south of Granville Center 35 or 40 feet of gray, sand shales and sandstone outcrop near the brow of the hill just west of th highway. This outcrop lies near the axis of the anticline and show no dip. This locality is about 2 miles north of the Gulf Brook se tion, and the beds represent a horizon somewhere near the base that section. The faunule which they contain includes the f lowi species:

Faunule of Granville Center section (1455 B).

[a, abundant; c, common; r, rare.]

1. Stropheodonta (Douvillina) mucronata (r).
2. Chonetes scitulus (a).
3. Productella speciosa (r).
4. Dalmanella tioga (c).
5. Leiorhynchus sinuatum (c).
6. Cryptonella sp. (c).
7. Atrypa aspera (c).
8. A. reticularis (c).
9. Spirifer mesistrialis (r).
10. Delthyris mesicostalis (a).
11. Ambocœlia gregaria (c).
12. Edmondia philipi (r).
13. E. subovata (r).
14. Nucula corbuliformis (r).
15. Palæoneilo plana (r).
16. Leptodesma lichas (a).
17. L. potens (c).
18. Leiopteria cf. sayi (a).
19. Pterinopecten vertumnus (r).
20. Goniophora chemungensis (c).
21. Cypricardella gregaria (c).
22. Bellerophon (Ptomatis?) rudis (c).
23. Pleurotomaria (Clathrospira?) capillaria (a).
24. Tentaculites cf. bellulus (a).
25. Manticoceras patersoni (r).

The presence in this fauna of such Hamilton species as *Cypricardella gregaria*, *Nucula corbuliformis*, *Pterinopecten vertumnus*, and other species having close affinities to, if not identical with, Hamilton species is worthy of note. The general character of the fauna, however, indicates an horizon near the boundary between the Nunda and the Chemung faunas, but above the base of the Chemung formation. It contains six of the fifteen diagnostic Chemung species named on p. 57.

Holonema rugosa Clayp									
(?) Holoptichius filosus Cope									
Onychodus sp									
PLANTÆ.									
Psilophyton sp							r		

SOUTH MOUNTAIN SECTION.

By E. M. Kindle.

A small ravine descending from the summit of South Mountain, opposite Leroy, exposes a section directly across Towanda Creek Valley, opposite the Gulf Brook section. The alluvium of the valley conceals about 450 feet of beds lying between the top of the Gulf Brook and the base of the South Mountain sections. About 300 feet of these concealed beds are exposed in the Towanda Narrows section. The South Mountain section continues the exposures of the previously described sections up to the Barclay coal bed. South Mountain is a synclinal mountain, and the strata on the north face, where this section was taken, have a very small dip to the south, the maximum being 10° at the base of the section.

The section is as follows:

Section 1455 C, at South Mountain, Bradford County, Pa.

	Feet.
31. Hard, massive, white to gray coarse sandstone, locally conglomeratic (outcropping on south brow of mountain)	20
30. Covered (estimated)	100
29. Thin-bedded gray sandstone	6
28. Covered	8
27. Shaly gray sandstone	15
26. Gray calcareous sandstone with carbonate of iron concretions and clay fragments scattered throughout	3
25. Grayish-green flags	4
24. Red and green shale	15
23. Red shale	10
22. Green thin-bedded sandstone	40
21. Red shale	28
20. Green sandstone	1
19. Red shale	5
18. Green thin-bedded sandstone	55
17. Red shale	12
16. Green to gray flaggy sandstone	15
15. Red shale	8
14. Green sandstone	3
13. Red shale	5
12. Flaggy green sandstone	105
11. Red shale	6
10. Flaggy green micaceous sandstone	110
9. Thin-bedded red and green sandstone	188
8. Reddish sandstone with fish remains	1
7. Thin-bedded red and green sandstone	72
6. Thin-bedded red sandstone (exposed in series of cascades)	115
6. Fish bed [a]	2
5. Thin-bedded red sandstone	35
4. Shaly red sandstone	25

[a] The fish bed, No. 6, was not seen in the section, but outcrops 300 yards to the west on the Rose Holcombe land.

	Feet.
3. Red shale	15
2. Shaly red sandstone with traces of plants	10
1. Covered from the level of Towanda Creek	150
Total	1,111

About 3 miles west of the South Mountain section 30 feet or more of dark-red shale outcrops in the Cold Spring road near the summit of the north face of the mountain. This shale probably belongs in the partly covered zones Nos. 28–30 of the above section and represents apparently the Mauch Chunk formation.

The peculiar calcareous bed, No. 26 of the section, agrees in its lithologic characters and horizon with a somewhat thicker bed of siliceous limestone in the Armenia Mountain and Tioga sections, viz, 1458 B59, called the Armenia limestone lentil of the Oswayo formation (see 127).

FAUNA OF SOUTH MOUNTAIN SECTION.

Careful search failed to discover any invertebrate fossils in the beds of this section. Fish remains, however, occur in abundance in at least two horizons. In zone 6, about 16 inches of the bed consist largely of a mass of the plates of *Bothriolepis leidyi.* Fragments of fish plates, probably *B. leidyi*, occur also in zone 8, 425 feet above the base of the section. Above this no traces of animal remains were found.

TOWANDA NARROWS SECTION.

By E. M. Kindle.

At the "Narrows," about 1 mile below Franklindale post-office, Towanda Creek has exposed a series of beds lying somewhat higher than those which terminate the Gulf Brook section. The beds have a southerly dip which increases rapidly toward the north. The outcrops continue back to the limestone horizon of the Franklindale beds, along a small brook which joins Towanda Creek just above the "Narrows." This limestone of the Franklindale beds affords a good stratigraphic basis for the comparison of the two sections. Comparing the beds in the two sections, which lie above this horizon, it is seen that the Towanda Narrows section extends more than 300 feet above the top of Gulf Brook section. The following section begins with the lowest outcrops near the point where the highway crosses a small brook, one-third of a mile north of the "Narrows."

Section 1456 A, at Towanda Narrows.

	Ft.	in.
40. Soft olive-green shale	10	0
39. Dull brownish-red sandstone	15	0
38. Olive-gray to purple micaceous thin-bedded sandstone	10	0
37. Red shale	3	0
36. Reddish-brown sandstone	1	8
35. Red and green shale	15	0

	Ft.	in.
34. Red to greenish sandstone and shale	6	0
33. Olive-gray micaceous sandstone, weathering brownish	25	0
32. Soft greenish sandy shale	6	0
31. Covered	65	0
30. Olive-gray sandy shale	12	0
29. Soft olive-gray shale	10	0
28. Massive olive-brownish sandstone with large concretions at base	5	0
27. Reddish sandstone and olive-gray shale interbedded	25	0
26. Olive-gray sandy shale	28	0
25. Dark reddish-brown, thin-bedded sandstone with some thin layers of greenish gray shale (dip 12° S.)	40	0
24. Covered	65	0
23. Bluish-gray flags (end of gorge, dip 25° S.)	100	0
22. Olive-gray thin-bedded sandstone	190	0
21. Olive-gray to reddish shales	40	0
20. Gray to reddish limestone	4	0
19. Red sandy shale	4	0
18. Calcareous hard red sandstone	2	0
17. Gray to purple limestone	4	6
16. Hard olive-gray sandstone (dip 60° S.)	15	0
15. Dark red, rather soft shale	12	0
14. Olive-gray sandy beds	10	0
13. Covered	6	0
12. Gray sandstone	1	0
11. Red shaly sandstone	3	0
10. Gray to reddish thin-bedded sandstone	30	0
9. Dark-red sandstone	3	0
8. Bluish-gray fossiliferous limestone	1	0
7. Covered	4	0
6. Bluish-gray sandstone, with *Sp. disjunctus*, etc	4	0
5. Dark red-brown sandstone	3	6
4. Gray shale	0	6
3. Dark reddish-brown sandstone with much iron	3	0
2. Covered	18	0
1. Gray sandy flags	15	0
	815	2

FAUNA OF TOWANDA NARROWS SECTION.

Many zones of this section contain an abundance of fossils, but lack of time prevented a detailed study of them. Fossils were collected from but one zone, the highest in the section, which affords the following faunule:

Faunule of zone 40 of Towanda Narrows section (1456 A).

[a, abundant; c, common; r, rare.]

1. Orbiculoidea lodiensis var. media (r).
2. Orthothetes chemungensis (r).
3. Productella lachrymosa (a).
4. Schizophoria striatula (c).
5. Camarotœchia stephani (a).
6. Cryptonella eudora (r).
7. Atrypa reticularis (r).
8. Delthyris mesicostalis (r).
9. Spirifer disjunctus (a).
10. Sphenotus sp. (r).
11. Leptodesma sp. (r).

The fauna is chiefly of interest as showing the presence of a Chemung fauna after sediments of strongly Catskill type have made their appearance in the section.

FORMATIONAL CORRELATION OF LEROY SECTION.

By E. M. Kindle.

The sections which have been described from exposures in the vicinity of Leroy give a connected section from the Sharon conglomerate down to the lowest beds exposed in the Towanda anticline, aggregating a thickness of 2,902 feet. The section may be divided, with reference to its more prominent lithological characteristics, into the following divisions:

General divisions of the Leroy section.

	Feet.
7. Coarse gray or white sandstone conglomerate (Sharon conglomerate)	20
6. Soft red shales (Mauch Chunk)	30
5. Red and greenish sandstones and shales, green beds predominating (Oswayo)	712
4. Red and green sandstones and shales, the red beds predominating (Cattaraugus or Catskill)	653
3. Drab-colored shales and sandstone with some highly ferruginous bands (Chemung)	400
2. Purple or reddish sandstone and shale interbedded with heavy beds of limestone (Franklindale beds)	160
1. Gray arenaceous shales and thin bedded sandstones (Chemung)	927
	2,902

There is nothing in the uninterrupted sequence of sandy shales and sandstones which make up the first 900 feet of the section to lead to any sudden change in the faunas. We may therefore expect to find, as we do in this section, that many representatives of the Ithaca fauna have continued on for some time after the appearance of Chemung types. The Ithaca fauna is an indigenous fauna in eastern New York, having been derived chiefly from the Hamilton. The Chemung represents a later development of the same fauna with the addition of certain foreign forms, as *Spirifer disjunctus.* This species first appears in the section about 700 feet above the base. *Delthyris mesicostalis*, which is a characteristic Chemung form, appears near the base of the section. The Ithaca element of the fauna is seen in the presence of such forms as *Sp. mesistrialis*, which indicates an overlapping of the Chemung and Ithaca faunas. The appearance near the base of the section of a form of so much zonal significance as *Delthyris mesicostalis* with well-developed medial septum seems to justify the correlation of the lowest division of the section with the Chemung. The Ithaca species which have transgressed the normal upper limit of that fauna nearly all disappear in the first 500 feet of the section,

The Chemung fauna continues for 800 feet above the lowest reddish beds. Its highest appearance is in beds which lithologically are of a decided Catskill type. Catskill fishes are found in the red shales after the Chemung fauna has entirely disappeared. These remains, however, do not continue to the upper limit of the Catskill type of sediments.

After the disappearance of Devonian fossils from the Leroy section the beds are entirely barren, so that there are no paleontological data for drawing the line between the Devonian and Carboniferous. In the absence of definite paleontological evidence the Devono-Carboniferous line may be drawn tentatively between divisions four and five of the generalized section, which corresponds to the base of the Oswayo—the Pocono of the Pennsylvania survey. The evidence of sections farther west, to be described later, seems to favor this correlation.

COMMENTS ON CORRELATION OF THE LEROY SECTION.

By H. S. Williams.

The first zone paleontologically includes the faunules 1 to 6 with *Pholadella radiata* and recalls the early stage of the Chemung as it appears in the Ithaca and Waverly quadrangles of New York, with a recurrent Hamilton fauna, and before the Chemung fauna is represented in full force.

From 7 up to 39 inclusive is a zone holding the *Stropheodonta* (*Douvillina*) *mucronata* fauna with *Delthyris mesicostalis*, *Spirifer mesistrialis*, and *Dalmanella carinata*, but without *Spirifer disjunctus;* while above, from faunule 43 to the top, *Spirifer disjunctus* occurs abundantly in almost all the fossiliferous zones, but the other spirifers are wanting and the pelecypods are rare compared with their frequent appearance in the lower zone.

It is probable that the first zone, including the lower 600 feet of this section, represents the fossiliferous zone which was called "Lower Chemung fauna" in 1884,[a] while the second zone represents the "typical Chemung" of that classification and the 1,100 feet of sediment may carry the strata up as high or higher than the horizon where the red Catskill type of sedimentation first appears in the Bradford County section at Ulster.[b]

The prominence of the calcareous beds, the dominance of *Cryptonella* in some zones, and the fish fauna are conspicuous features of this upper zone.

[a] Trans. Am. Inst. Min. Eng., vol. 16, p. 946. Also quoted in Doctor Kindle's paper on the Relation of the fauna of the Ithaca group to the faunas of the Portage and Chemung, Bull. Am. Paleontology, vol. 2, 1896, p. 9.

[b] On the fossil faunas of the upper Devonian along the meridian of 76° 30′ from Tompkins County, N. Y., to Bradford County, Pa: Bull. U. S. Geol. Survey No. 3, p. 27.

It is to be noted that in the one continuous section of Gulf Brook the Chemung fauna has a range of 1,200 feet. If the correlation of the Towanda Narrows section with its upper part be correct, the range is extended 300 feet higher. The estimate of the length of this range, made on the basis of the section along the 76° 30′ meridian, was 1,200 feet; but at that time (1884) the upper limit of the Chemung was put where the red beds first appear in force. It is now known that the Chemung fauna does not everywhere stop at that horizon. It is, however, quite probable that the Leroy section covers the greater part of the total range of the Chemung fauna for that region, which by measurement is 1,700 feet of strata.

THE TIOGA SECTION.

By E. M. Kindle.

Tioga River cuts squarely across the axis of the Crooked Creek synclinal mountain, just south of the village of Tioga. North of the town, the southward-dipping Chemung beds are well exposed on the east bank of the river. The following section is based upon the outcrops between the wagon bridge, two-thirds of a mile north of the town, and the Pennsylvania Railroad station, and on those in and near the highway between Tioga and the summit of the mountain, 4 miles east of Tioga:

Section 1460 A, at Tioga, Pa.

	Feet.
56. White coarse sandstone with numerous small angular quartz pebbles..	20±
[a]55. Black carbonaceous shale	1±
54. Coal ? (a few inches reported)	?
53. Covered (place of Mauch Chunk)	45±
52. Mottled arenaceous gray limestone with lumps of shale and fish teeth..	10
51. Covered	10±
50. Irregular-bedded coarse buff sandstone, some layers with numerous carbonized plants	10
49. Covered	10
48. Red shale	10
47. Light-green thin-bedded micaceous sandstone	45
46. Greenish-gray and red sandstone and shales mostly covered. (Oswayo and Cattaraugus)	960±
45. Red and gray beds mostly concealed. (Cattaraugus-Chemung transition)	100
44. Gray thin-bedded sandstone	5
43. Covered	15
42. Drab-colored thin-bedded sandstone (partly concealed)	16
41. Covered	4
40. Thin-bedded drab sandstone	12
39. Thin-bedded drab sandstone	16
38. Covered	32

[a] Nos. 47 to 55 of the section are exposed in a shaft, drift, and quarry near the residence of A. H. Rawson.

	Feet.
37. Gray to reddish thin-bedded sandstone	25
36. Covered	12
35. Red highly ferruginous sandstone	2
34. Dull-reddish to olive shale and sandstone	13
33. Bed of *Sp. disjunctus* shells	2
32. Olive-gray sandstone	5
31. Covered	5
30. Dull-reddish shale and thin-bedded sandstone	40
29. Thin-bedded gray sandstone	20
28. Olive-gray shale with thin bands of sandstone	30
27. Gray to salmon-brown thin-bedded sandstone with concretionary structure	25
26. Dark-gray shale and shaly sandstone	20
25. Covered	6
24. Dull-reddish shale and sandstone with fossiliferous band	4
23. Covered	5
22. Dull-reddish to gray shale	18
21. Dark-reddish thin-bedded sandstone	15
20. Dull salmon-brown to olive shale	10
19. Olive-gray shale and thin-bedded sandstone, some of beds with dull-reddish tint	30
18. Olive-gray and dull-reddish shale	20
17. Covered	10
16. Olive-gray and dull-reddish thin-bedded sandstone interbedded	18
15. Covered	5
14. Thin-bedded sandstone	4
13. Gray to reddish shale and sandstone	9
12. Calcareous bed of fossils	2
11. Gray sandstone	3
10. Beds of fossil shells in drab calcareous sandstone	3
9. Dull-brownish red thin-bedded sandstone	3
8. Sandstone and shale with concretions	4
7. Gray sandstone	4
6. Gray shale and sandstone	5
5. Soft gray clay shale	10
4. Covered	35
3. Thin-bedded drab sandstone	14
2. Covered	15
1. Brownish-gray thin-bedded sandstone	20
	2,315

FAUNULES OF THE TIOGA SECTION.

Zone 1 of Tioga section (1460 A).—The 20 feet of sandstone exposed at the bridge, two-thirds of a mile north of Tioga, contains the following species:

Faunule of zone 1 of Tioga section (1460 A).

[a, abundant; c, common; r, rare.]

1. Stropheodonta (Douvillina) inæquistriata (c).
2. S. (Leptostrophia) perplana var. nervosa (a).
3. Strophonella cælata (a).
4. Chonetes cf. vicinus (c).
5. Atrypa reticularis (r).
6. A. spinosa (c).
7. Sphenotus cf. archæformis (r).
8. Macrodon cf. chemungensis (r).
9. Leptodesma lichas (a).
10. Schizodus chemungensis (r).
11. S. oblatus (r).
12. Modiomorpha cf. quadrula (r).
13. Manticoceras cf. complanatum (r).

The Chemung characteristics of this faunule, which is the lowest in the section, indicate that the section includes nothing lower than Chemung beds.

Zone 7 of Tioga section (1460 A).—Very few fossils occur in the zones 2 to 6. The following species are found in zone 7, 100 feet above the base of the section:

Faunule of zone 7 of Tioga section (1460 A).

[a, abundant; c, common; r, rare.]

1. Stropheodonta (Douvillina) mucronata (a).
2. Orthothetes chemungensis (r).
3. Atrypa spinosa (c).
4. Spirifer disjunctus (r).

Zones 8 and 9 of Tioga section (1460 A).—These zones appear to be without fossils.

Zone 10 of Tioga section (1460 A).—The species noted in this zone are as follows:

Faunule of zone 10 of Tioga section (1460 A).

[a, abundant; c, common.]

1. Stropheodonta (Douvillina) mucronata (c).
2. Atrypa spinosa (c).
3. Spirifer disjunctus (a).
4. Fish remains (c).

The extremely mucronate form of *Sp. disjunctus* is found in this zone.

Zone 12 of Tioga section (1460 A).—This zone contains a mass of fossils, mostly shells of *Sp. disjunctus.*

Zones 13 to 15 of Tioga section (1460 A).—Fossils are comparatively scarce in these zones.

Zone 16 of Tioga section.—The faunule of this zone comprises the following species:

Faunule of zone 16 of Tioga section (1460 A).

[a, abundant; c, common; r, rare.]

1. Strophonella cælata.
2. Orthothetes chemungensis.
3. Productella cf. lachrymosa (c).
4. Schizophoria striatula (a).
5. Spirifer disjunctus (a).
6. Glossites lingualis (r).
7. Palæoneilo filosa (r).
8. Platyceras sp. (r).

Zone 18 of Tioga section (1460 A).—This zone affords the following species:

Faunule of zone 18 of Tioga section (1460 A).

[a, abundant; c, common; r, rare.]

1. Stropheodonta (Douvillina) mucronata (r).
2. Strophonella cælata (c).
3. Orthothetes chemungensis (r).
4. Productella lachrymosa (a).
5. Schizophoria striatula (a).
6. Atrypa spinosa (r).
7. Cyrtina hamiltonensis (r).
8. Spirifer disjunctus (a).
9. Leptodesma lichas (c).
10. L. sp. (r).
11. Bellerophon sp. (r).

Zone 24 of Tioga section (1460 A).—The 80 feet of beds intervening between zones 18 and 24 contain few fossils, the species being forms common to these two zones. The species occurring in zone 24 are as follows:

Faunule of zone 24 of Tioga section (1460 A).

[a, abundant; c, common; r, rare.]

1. Zaphrentis sp. (r).
2. Stropheodonta (Douvillina) mucronata (r).
3. S. sp. (a).
4. Strophonella cælata (r).
5. Orthothetes chemungensis (r).
6. Productella sp. (r).
7. Spirifer disjunctus (a).

Zone 29 of Tioga section (1460 A).—The species occurring in this zone are as follows:

Faunule of zone 29 of Tioga section (1460 A).

[a, abundant; c, common; r, rare.]

1. Orthothetes chemungensis (c).
2. Chonetes setigerus (r).
3. Productella lachrymosa (a).
4. Schizophoria striatula (c).
5. Dalmanella tioga (r).
6. Camarotœchia stephani (c).
7. Spirifer disjunctus (a).
8. Delthyris mesicostalis (a).
9. Glossites lingualis (r).

Zone 33 of Tioga section (1460 A).—A mass of the shells of *Sp. disjunctus* comprises the greater part of this zone. The species recognized in it are as follows:

Faunule of zone 33 of Tioga section (1460 A).

1. Productella lachrymosa (rare).
2. Camarotœchia stephani (rare).
3. Spirifer disjunctus (abundant).

Zone 34 of Tioga section (1460 A).—Only three species were recognized in this zone.

Faunule of zone 34 of Tioga section (1460 A).

1. Orthothetes chemungensis (common).
2. Spirifer disjunctus (common).
3. Orthoceras sp. (rare).

Zone 35 of Tioga section (1460 A).—Two feet of very ferruginous red sandstone hold the following faunule:

Faunule of zone 35 of Tioga section (1460 A).

[a, abundant; c, common; r, rare.]

1. Orthothetes chemungensis (r).
2. Camarotœchia sp. (r.)
3. Spirifer disjunctus (a).
4. Delthyris mesicostalis (r).
5. Ambocœlia gregaria (c).
6. Athyris cf. angelica (r).
7. Mytilarca chemungensis (r).
8. Aviculopecten duplicatus (r).
9. A. striatus (r).

Zone 39 of Tioga section (1460 A).—Seventy feet above the preceding faunule the following association of species occurs:

Faunule of zone 39 of Tioga section (1460 A).

[a, abundant; c, common; r, rare.]

1. Productella lachrymosa (a).
2. Schizophoria striatula (c).
3. Camarotœchia stephani (c).
4. Delthyris mesicostalis (c).
5. Ambocœlia gregaria (c).
6. Athyris angelica (r).
7. Aviculopecten cf. cancellatus (r).

Zone 42 of Tioga section (1460 A).—This zone, nearly 600 feet above the base of the section, contains nearly the same association of species as the preceding faunule, 39, 60 feet below it. The species are as follows:

Faunule of zone 42 of Tioga section (1460 A).

[c, common; r, rare.]

1. Orthothetes chemungensis (c).
2. Productella lachrymosa (r).
3. Schizophoria striatula (c).
4. Camarotœchia stephani (r).
5. Delthyris mesicostalis (c).
6. Ambocœlia gregaria (c).
7. Athyris angelica (c).
8. Sphenotus sp. (r).

Zone 44 of Tioga section (1460 A).—Fifteen feet above zone 39 occurs the highest faunule secured from the section. It contains the following species:

Faunule of zone 44 of Tioga section (1460 A).

[a, abundant; c, common; r, rare.]

1. Stropheodonta sp. (r).
2. Productella lachrymosa (a).
3. Schizophoria striatula (a).
4. Camarotœchia stephani (c).
5. Leiorhynchus mesicostale (r).
6. Atrypa reticularis (r).
7. Spirifer disjunctus (c).
8. Delthyris mesicostalis (c).
9. Ambocœlia gregaria (c).
10. Athyris angelica (c).
11. Sphenotus contractus (r).
12. Glossites procerus (r).
13. Mytilarca chemungensis (c).
14. Actinopteria sp. (r).

The beds immediately following this zone are concealed, and the Chemung fauna may continue on through 50 feet or more of the gray or reddish beds succeeding it. After the typical red Catskill beds are reached, however, no trace of fossils appears beyond some obscure plant remains.

The accompanying chart exhibits the range of the several species comprising the fauna of this section.

Faunal chart of the Tioga section (1460 A), Tioga County, Pa.

[a, abundant; c, common; r, rare.]

vosa	a																														
Stropheodonta sp.													r																		r
Strophonella cælata	a							c	c				r																		
Orthothetes chemungensis					r			a	r				r					c				c								c	
Chonetes cf. vicinus	c																														
C. scitulus																														r	
C. setigerus																		r													
Productella lachrymosa									a				r					a			r					a				r	a
P. cf. lachrymosa								c																							
Schizophoria striatula								c	a									c								c				c	a
Dalmanella tioga																		r													
Camarotoechia stephani																		r			r	r				c				r	c
Leiorhynchus mesacostale																															r
Atrypa reticularis	r																														r
A. spinosa	c				c	c			r																						
Cyrtina hamiltonensis									r																						
Spirifer disjunctus					r	a		a	a				a					a			a	c									c

Delthyris mesacostalis																	a				r				c				c	c
Ambocœlia gregaria																					c				c				c	c
Athyris angelica																									r				c	c
A. cf. angelica																					r									
MOLLUSCA.																														
Glossites lingualis							r										r													
G. procerus																														r
Palæoneilo filosa							r																							
Macrodon cf. chemungensis	r																													
Leptodesma lichas	a							c																						
L. sp								r									r													
Mytilarca chemungensis																					r									c
Actinopteria sp																														r
Schizodus chemungensis	r																													
S. oblatus	r																													
Aviculopecten duplicatus																					r									
A. cf. cancellatus																									r					
A. striatus																					r									
Modiomorpha cf. quadrula	r																													
Orthoceras sp																					r									
Manticoceras cf. complanatus	r																													
Bellerophon sp								r																						
Platyceras sp							r																							
PISCES.																														
Fish bones (fragments)						c																								

ORE-BED SECTION, MANSFIELD.

By E. M. KINDLE.

Chemung rocks are exposed at frequent intervals along the public highway which passes the old iron-ore pit, 3 miles west of Mansfield. The following section is constructed from exposures along this road between the old ore pit and Tioga River.

Section 1459 B at the ore-bed road, Mansfield.

	Ft.	in.
22. Surface clay	5	0
21. Brown, soft shaly sandstone	0	8
20. Gray sandy shale	10	0
19. Red oolitic iron ore	0	18–24
18. Reddish calcareous sandstone (in old ore pit)	0	6
17. Concealed	50	0
16. Brownish-gray sandstone	5	0
15. Gray shale and covered	60	0
14. Shaly sandstone and shale fossiliferous at top	25	0
13. Concealed	10	0
12. Dard-gray clay shale and shaly sandstone	5	0
11. Dark shaly sandstone	1	0
10. Covered	119	0
9. Thin-bedded and shaly sandstone	25	0
8. Covered	6	0
7. Bluish-gray clay shale	8	0
6. Covered	20	0
5. Thin-bedded sandstone	6	0
4. Covered	140	0
3. Drab sandy shale and flaggy sandstone	22	0
2. Covered	42	0
1. Bluish-gray shale (in bed of creek)	6	0

FAUNULES OF THE ORE-BED ROAD SECTION, MANSFIELD.

Zone 3 of Mansfield section (1459 B).—This zone holds the lowest faunules noted in the section, comprising the following species:

Faunule of zone 3 of Mansfield section (1459 B).

[a, abundant; c, common; r, rare.]

1. Strophonella cælata (c).
2. Orthothetes chemungensis (a).
3. Schizophoria striatula (a).
4. Atrypa spinosa (a).
5. Cyrtina hamiltonensis (r).
6. Spirifer disjunctus (a).
7. Byssopteria radiata (c).
8. Pterinea sp. (r).

Zone 5 of Mansfield section (1459 B).—The beds of zone 4, having a thickness of 140 feet, are not exposed. The species occurring in zone 5 are as follows:

Faunule of zone 5 of Mansfield section (1459 B).

[a, abundant; c, common; r, rare.]

1. Orthothetes chemungensis (a).
2. Productella lachrymosa (a).
3. Schizophoria striatula (c).
4. Camarotœchia contracta (a).
5. Spirifer disjunctus (a).
6. Delthyris mesicostalis (a).
7. Athyris angelica (a).
8. Leptodesma sp. (r).
9. Crenipecten cf. amplus (r).

Zone 9 of Mansfield section (1459 B).—The following species are found in zone 9, 34 feet above zone 5:

Faunule of zone 9 of Mansfield section (1459 B).

[a, abundant; c, common; r, rare.]

1. Productella lachrymosa (a).
2. Schizophoria striatula (r).
3. Camarotœchia contracta (a)
4. Delthyris mesicostalis (a).
5. Athyris angelica (c).
6. Aviculopecten rugæstriatus (r).

Zone 11 of Mansfield section (1459 B).—The greater part of the section between zones 9 and 11 is concealed. The following faunule is from a 1-foot bed 120 feet above the preceding faunule:

Faunule of zone 11 of Mansfield section (1459 B).

[a, abundant; c, common; r, rare.]

1. Orbiculoidea sp. (r).
2. Orthothetes chemungensis (c).
3. Productella lachrymosa (a).
4. Schizophoria striatula (a).
5. Camarotœchia contracta (c).
6. Cryptonella sp. (r).
7. Delthyris mesicostalis (a).
8. Ambocœlia gregaria (r).
9. Athyris angelica (a).
10. Sphenotus cf. rigidus (r).
11. Glossites cf. depressus (r).
12. Macrodon chemungensis (r).
13. Euomphalus sp. (r).
14. Loxonema sp. (r).

Zone 12 of Mansfield section (1459 B).—The 5 feet of shale and sandstone following zone 11 contain the following species:

Faunule of zone 12 of Mansfield section (1459 B).

[a, abundant; c, common; r, rare.]

1. Orthothetes chemungensis (c).
2. Chonetes setigerus (r).
3. Productella arctirostrata (r).
4. P. boydi (c).
5. P. lachrymosa (c).
6. Schizophoria striatula (a).
7. Camarotœchia contracta (a).
8. Spirifer disjunctus (r).
9. Delthyris mesicostalis (a).
10. Ambocœlia gregaria (r).
11. Athyris angelica (c).
12. Grammysia sp. (r).
13. Sphenotus contractus (r).
14. Leptodesma lichas (r).

The specimens referred to No. 7, have less angular plications and shallower sinus than specimens of *Camarotœchia contracta* from northwestern Pennsylvania. The shells show—

Plications in sinus, 3–4; generally 3.
Plications on fold, 4; rarely 5.
Plications on each valve, about 16.

Variation in No. 6 occurs chiefly in relation to shape of muscular impression in pedicle valve and in the ratio of length and width. The two latter characters are equal in some individuals. In many the width exceeds the length by one-fourth or more.

No. 9 shows considerable variability in this zone with reference to the number of plications. These vary from 13 to 29 on each valve. The length of the mesial septum is contained in the length of the shell from two to three and a half times. Of 23 specimens examined 22 have one plication and one has a double plication in the sinus. All of the specimens show a double fold except one, which has a third plication weakly developed on the fold.

Zone 15 of Mansfield section (1459 B).—About 20 feet above the preceding faunule were found the following species:

Faunule of zone 15 of Mansfield section (1459 B).

[a, abundant; c, common; r, rare.]

1. Productella lachrymosa (c).
2. Schizophoria striatula (r).
3. Camarotœchia stephani (a).
4. Delthyris mesicostalis (a).
5. Ambocœlia gregaria (r).
6. Athyris angelica (r).
7. Sphenotus contractus (c).
8. Edmondia philipi (c).
9. Aviculopecten sp. (r).

Zone 18 of Mansfield section (1459 B).—One hundred and fifteen feet above zone 14 a thin calcareous bed appears, underlying the iron-ore bed. Only three species were collected from it.

Faunule of zone 18 of Mansfield section (1459 B).

[a, abundant; c, common.]

1. Productella lachrymosa (c).
2. Camarotœchia stephani (c).
3. Spirifer disjunctus (a).

Zone 19 of Mansfield section (1459 B).—Eighteen to 24 inches of red hematite comprise this zone. The only fossils found in it are *Productella lachrymosa* and *Spirifer disjunctus*, which are common.

Zone 21 of Mansfield section (1459 B).—Ten feet above the iron ore the highest faunule of the section appears. It contains the following species:

Faunule of zone 21 of Mansfield section (1459 B).

[a, abundant; c, common; r, rare.]

1. Orthothetes chemungensis (r).
2. Productella lachrymosa (c).
3. Camarotœchia sappho (a).
4. Spirifer disjunctus (c).

The section as a whole shows a fauna of distinctly Chemung type, *Cyrtina hamiltonensis* is the only Hamilton survivor appearing in it. The faunules of the different parts of the section do not offer any sharp contrasts in composition. The accompanying chart, showing the distribution of species in the section, indicates that dominant species, or those appearing abundantly or commonly in any zone, are usually found to range through a number of zones or the entire section.

Faunal chart of the ore-bed road section, Mansfield, Tioga County, Pa. (*1459 B*).

[a, abundant; c, common; r, rare.]

	Gray sandy shale and sandstone (Chemung).															Iron ore.	
	1	2	3	4	5	6	7	8	9	10	11–13	14	15	16	17	18–22	
				100 ft.	200 ft.					300 ft.	400 ft.			500 ft.			
MOLLUSCOIDEA.																	
Orbiculoidea sp											r						
Strophonella cælata			c														
Orthothetes chemungensis			r		a						c						r
Chonetes setigerus											r						
Productella arctirostrata											r						
P. boydi											c						
P. lachrymosa					a				a		a	c				c	c
Schizophoria striatula			a		c				r		a	r					
Camarotœchia contracta					a				a		a						
C. stephani												a					
C. sappho																	a
Cryptonella sp											r						
Delthyris mesicostalis					a				a		a	a					
Atrypa spinosa			a														
Cyrtina hamiltonensis			r														
Spirifer disjunctus			a		r						r					a	c
Ambocœlia gregaria											r	r					
Athyris angelica					a				c		a	r					
MOLLUSCA.																	
Sphenotus contractus											r	c					
S. cf. rigidus											r						
Grammysia sp											r						

Glossites cf. depressus																				r										
Edmondia philipi																						c								
Macrodon chemungensis																				r										
Leptodesma sp											r																			
L. lichas																				r										
Pterinea? sp				r																										
Byssopteria radiata				c																										
Aviculopecten rugæstriatus														r																
A. sp																						r								
Crenipecten cf. amplus											r																			
Euomphalus sp																				r										
Loxonema sp																				r										

CANOE CAMP SECTION.

By E. M. KINDLE.

The section at Canoe Camp begins at the lower cascade in Canoe Camp Creek, near Canoe Camp, Tioga County, Pa., and runs up the ravine and sidehill to the old ore pits on south side of Butts Hill.

Section 1459 A, at Canoe Camp, Pa.

	Ft.	In.
18. Thin-bedded sandstone and shale, olive gray, with some reddish bands near base	12	0
17. Fine-grained oolitic iron ore (thickness concealed)		
16. Concealed	135	0
15. Gray shale	0	20
14. Concealed	4	0
13. Gray shale	2	0
12. Hard gray sandstone	0	8
11. Concealed	2	0
10. Gray soft shale with some bands of hard sandstone	5	6
9. Blue calcareous sandstone full of fossils	0	6
8. Gray shale	6	0
7. Thin-bedded sandstone and shale	6	0
6. Thin-bedded sandstone and bluish-gray shale, with corals	10	0
5. Bluish-gray sandstone full of fossils	0	{8–10
4. Drab-colored sandy shale	17	0
3. Concealed (above fall in creek)	140	0
2. Thin-bedded shaly drab sandstone and shale	5	0
1. Grayish-drab sandstone and shale	11	0

FAUNULES OF THE CANOE CAMP SECTION.

The fanules of the Canoe Camp section are all Chemung. They are as follows:

Zone 1 of Canoe Camp section (1459 A).—The lowest zone of the section, which is exposed at the cascade in Canoe Camp Creek, contains the following faunule:

Faunule of zone 1 of Canoe Camp section (1459 A).

[a, abundant; c, common; r, rare.]

1. Strophonella cælata (r).
2. Orthothetes chemungensis (c).
3. Productella lachrymosa (c).
4. Schizophoria striatula (c).
5. Spirifer disjunctus (a).
6. Leptodesma creon.
7. Cypricardella cf. bellistriata (r).

Zone 2 of Canoe Camp section (1459 A).—Five feet of shaly sandstone immediately following the preceding zone contains the following species:

Faunule of zone 2 of Canoe Camp section (1459 A).

[a, abundant; c, common; r, rare.]

1. Stropheodonta (Douvillina) mucronata (c).
2. Strophonella cælata (c).
3. Orthothetes chemungensis (c).
4. Productella cf. lachrymosa (r).
5. Schizophoria striatula (a).
6. Atrypa spinosa (r).
7. Cyrtina hamiltonensis (r).
8. Spirifer disjunctus (a).

The *Sp. disjunctus* of this and the preceding zone belongs to the wide mucronate type of the species. *Schizophoria striatula* and *Stropheodonta* (*Douvillina*) *mucronata* are each represented by individuals which are less than half the normal size of the species.

Zone 5 of Canoe Camp section (*1459 A*).—The outcrops of this and the next zone are in the ravine on the south side of Butts Hill. The faunule comprises the following species:

Faunule of zone 5 of Canoe Camp section (*1459 A*).

[a, abundant; c, common; r, rare.]

1. Stropheodonta (Douvillina) mucronata (c).
2. Strophonella cælata (r).
3. Chonetes sp. (r).
4. Productella cf. lachrymosa (c).
5. Atrypa aspera (c).
6. Spirifer disjunctus (a).

Zone 6 of Canoe Camp section (*1459 A*).—This zone afforded the following species:

Faunule of zone 5 of Canoe Camp section (*1459 A*).

[a, abundant; c, common; r, rare.]

1. Zaphrentis cf. simplex (a).
2. Stropheodonta (Douvillina) mucronata (a).
3. Strophonella cælata (c).
4. Orthothetes chemungensis (a).
5. Atrypa spinosa (c).
6. Cyrtina hamiltonensis (r).
7. Spirifer disjunctus (a).
8. Byssopteria radiata (r).

Zone 18 of Canoe Camp section (*1459 A*).—The highest zone of the section, exposed just above the old ore pit, furnished the following species:

Faunule of zone 18 of Canoe Camp section (*1459 A*).

[c, common; r, rare.]

1. Productella lachrymosa (c).
2. Delthyris mesicostalis (c).
3. Athyris angelica (r).
4. Grammysia cf. circularis (r).
5. Leptodesma sp. (r).

Faunal chart of Canoe Camp section, Tioga County, Pa. (1459 A).

[a, abundant; c, common; r, rare.]

	Gray thin-bedded sandstone and shale.						Oolitic iron ore.	
	1 2	3 (100 feet.)	4	5–6	7–15 (200 feet.)	16 (300 feet.)	17	18
CŒLENTERATA.								
Zaphrentis cf. simplex				a				
MOLLUSCOIDEA.								
Stropheodonta (Douvillina) mucronata	c			c				
Strophonella cœlata	c			c				
Orthothetes chemungensis	a			a				
Chonetes sp				r				
Productella lachrymosa	c						c	
P. cf. lachrymosa				c				
Schizophoria striatula	a							
Delthyris mesicostalis							c	
Atrypa spinosa	r			c				
Spirifer disjunctus	a			a				
Cyrtina hamiltonensis	r			r				
Athyris angelica							r	
MOLLUSCA.								
Cypricardella cf. bellistriata	r							
Grammysia cf. circularis							r	
Leptodesma creon	c							
Leptodesma sp							r	
Byssopteria radiata				r				

CORRELATION OF THE TIOGA, MANSFIELD, CANOE CAMP, AND ARMENIA MOUNTAIN SECTIONS.

By E. M. Kindle.

The Tioga section includes the lowest and the highest beds exposed in the quadrangle, so far as known, extending from the Sharon conglomerate several hundred feet down into the Chemung. The upper third of the section is barren of fossils, except for a few fish teeth in the arenaceous limestone bed in the upper part of the section (1460 A52). This bed is of some importance, because its peculiar lithological features make its recognition possible whenever encountered over a considerable area. The best exposures of this bed and the associated shales and sandstones occur near the summit of Armenia Mountain, 2 miles west of Troy, in Bradford County. The section, from the highest beds exposed near the summit, is as follows:

Section 1458 B, at Armenia Mountain.

	Feet.
31. Greenish-gray coarse micaceous thin-bedded and cross-bedded sandstone	10
30. Concealed	20
29. Mottled light greenish-gray arenaceous limestone, with frequent lumps of shale and occasional fish remains	5
28. Thin-bedded greenish-gray sandstone, showing false bedding	20
27. Green sandy shale	5
26. Soft red shale	18
25. Heavy-bedded greenish-gray sandstone, tending to split easily and running into shale in a short distance	30
24. Greenish shale and thin-bedded sandstone	15
23. Greenish brecciated shale bed	1
22. Soft green shale	9
21. Green, coarse, heavy-bedded micaceous sandstone, with some plant remains and a few shale bands	35
20. Soft red clay, scarcely showing stratification	25
19. Bright-green sandstone	1
18. Soft red shale	5
17. Green and red shale	13
16. Soft red shale	10
15. Green heavy-bedded sandstone	4
14. Red soft argillaceous indistinctly stratified shale	11
13. Green massive sandstone	8
12. Red and green shale and sandstone, color varying rapidly at the same horizon	20
11. Red shale, green sandstone, and covered	140
10. Red shale, with an occasional band of sandstone, lower 20 feet covered	50
9. Red sandstone	5
8. Concealed	90
7. Cross-bedded red sandstone	10
6. Concealed	180
5. Red shale and sandstone	30
4. Red sandstone, full of worm (?) trails	25
3. Hard red sandstone, with numerous fish remains	3
2. Concealed	10
1. Red sandstone	6

The limestone (No. 29 of the section) contains probably not more than 25 per cent of lime, but since no other bed in the section above the Chemung contains an appreciable quantity of lime, it is regarded as a limestone. It will be designated the Armenia limestone lentil; it occurs in the upper part of the Oswayo formation.

The Armenia Mountain section lies about 14 miles southeast of the Tioga section and 10 miles northwest of the South Mountain section. The detailed Armenia section as given above may be safely assumed to represent closely the concealed upper part of the Tioga section. The Armenia limestone is easily recognizable in each of the three sections. The few fish remains occurring in this bed are of Carboniferous type. Below the Armenia limestone occasional plant remains are the only fossils seen until beds containing Catskill fishes are reached. The beds in which these fossils appear abundantly lie in the South Mountain section 797 feet below the horizon of the Armenia limestone and in the Armenia Mountain section 754 feet below the same horizon.

As yet no invertebrate paleontological data are available for drawing any sharp line of distinction between the Devonian and Carboniferous sediments. In the absence of entirely adequate data for determining this boundary it is perhaps most convenient and practicable to consider the latest appearance of Catskill fish remains as marking the end of the Devonian period. This horizon occurs in the section near the division line between the Cattaraugus and Oswayo of the Elkland-Tioga folio.

In the few sections in this region showing nearly continuous exposures from the Chemung fauna to the Sharon conglomerate there is seen to be very slight basis for a division on the basis of color, the red beds being nearly as common in the upper as the lower portions. It will be noted, however, in examining average sections where the greater part is covered that red beds *appear* to be most abundant in the lower third of the section. This is largely due to the fact that the lower beds are very generally tough sandstones which are apt to outcrop prominently, while the upper red beds are nearly all soft shales which are likely to outcrop less conspicuously, if at all. This tendency of the upper red beds to be soft shales and the lower to be tough, flaggy, and often cross-bedded sandstones is correlated with their faunal characteristics—the upper red and gray beds being, with the exception of the Armenia limestone, entirely barren of animal remains, while the lower contain numerous fish remains.

The invertebrate fauna, from the lowest beds of the section to its termination upon the appearance of sediments of Catskill type, is distinctly Chemung in character.

Most of the sections in the region about Mansfield are characterized by one or more beds of iron ore. There appear to be three of these

beds, but no single section shows more than two of them. Beds of similar character, but with a lower grade of ore, occur at the same horizon near Leroy.

The limestone facies represented in most of the sections of western Bradford County below the ferruginous sandstone and ore beds by the limestone of the Franklindale beds has almost entirely disappeared in the Tioga sections. It appears to be represented, however, at a few localities by a thin bed of limestone composed of shell fragments. A bed of this character not now exposed, which is said to be 5 or 6 feet in thickness, occurs in the hill 1 mile north of Mansfield. In the southeast corner of the county this limestone outcrops 2 or 3 miles east of Roaring Branch, along the Lycoming Creek wagon road.

While the Franklindale beds have thinned almost to the vanishing point west of the Tioga-Bradford county line, the iron-ore beds, which at Leroy accompany and lie above the Franklindale beds, have become more pronounced and carry a higher grade of ore. The peculiarities of the different ore beds are not sufficiently marked, either paleontologically or lithologically, to enable one to correlate with confidence the individual ore beds of the Mansfield region with those of the Leroy region; but that the Mansfield ore beds and intervening strata, as a whole, should be correlated with the ferruginous sandstones and ore beds at Leroy is indicated by the following considerations:

(1) The highest ore bed lies approximately at the same distance below the upper limit of fossils at Leroy and Mansfield.

(2) The iron ores and their associated strata represent the first appearance of red sedimentation in both districts.

(3) A limestone which is apparently the equivalent of that at Leroy is present at some localities in the ore-bed sections of the Mansfield region.

COMMENTS ON THE FAUNAS OF THE TIOGA, MANSFIELD, AND CANOE CAMP SECTIONS.

By H. S. Williams.

There are some interesting facts regarding the faunas associated with the red beds and iron-ore deposits in the eastern part of the Tioga quadrangle.

In each of the three sections examined in detail (Mansfield, Canoe Camp, and Tioga) there are two faunas which occur in succession, lapping a little, but in the main distinct in composition. This is shown by the following analysis of the faunas:

The first point noticed is that *Strophonella cælata* is conspicuous in the earlier zones of each section, while *Athyris angelica* is dominant in the higher faunules, and these two species do not occur together in

any of the faunules reported. Prominent among the associates of *Strophonella cælata* are *Stropheodonta* (*Douvillina*) *mucronata*, and in the lowest faunule of Tioga section, also *Stroph.* (*Leptostrophia*) *perplana* var. *nervosa*, and *Stropheodonta* (*Douvillina*) *inæquistriata*, *Spirifer disjunctus*, and *Atrypa spinosa*, none of which species are associated with *Athyris angelica*.

In the higher zone common associates with *Athyris* are *Delthyris mesicostalis*, and *Camarotœchia contracta*, neither of which is seen associated with *Strophonella*. *Schizophoria striatula*, *Productella lachrymosa*, and *Orthothetes chemungensis* are common to both faunas.

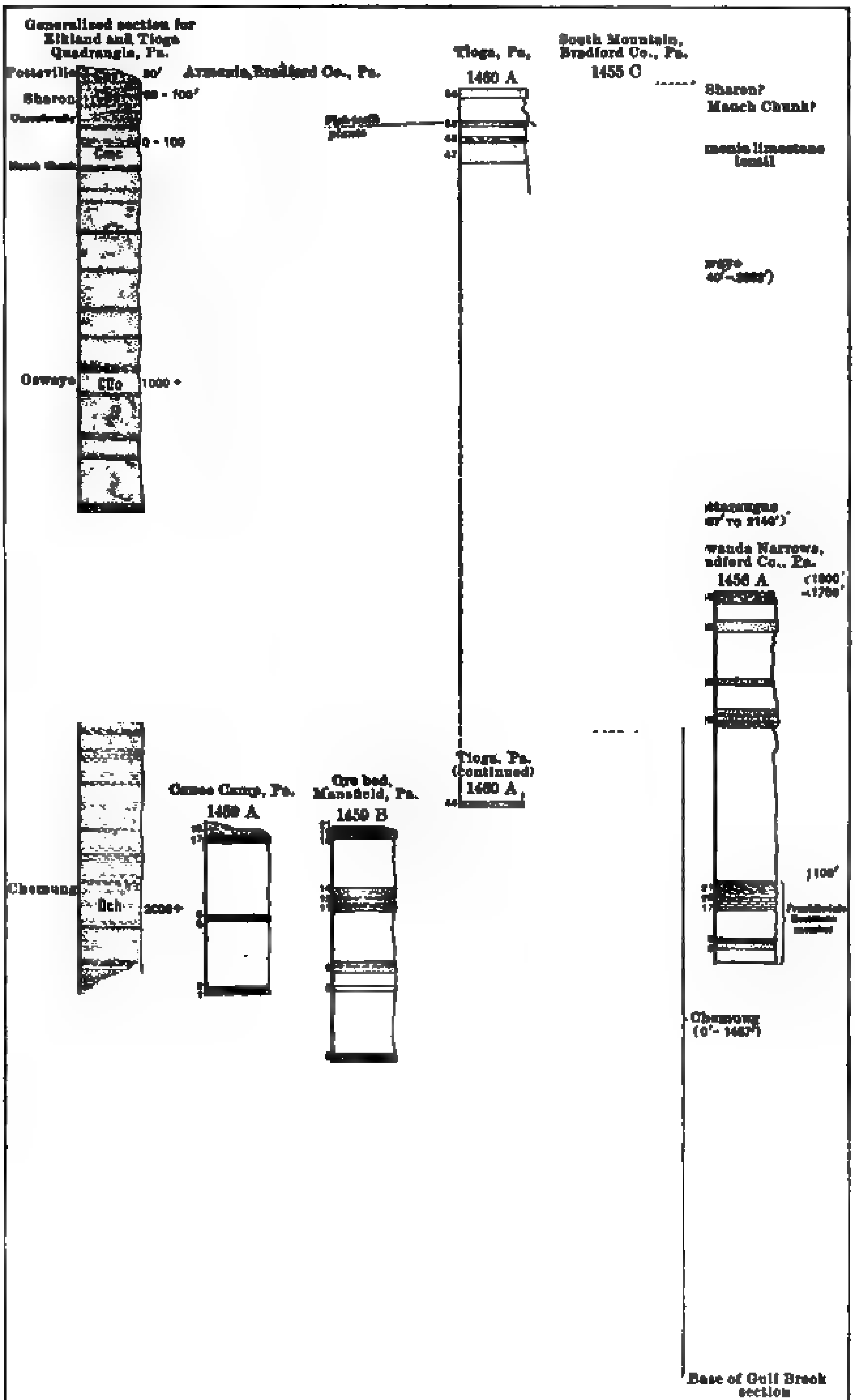
Athyris angelica is rare in the eastern extension of the Chemung fauna, but whether its absence is associated with the fact that the higher Chemung faunas are cut off in the east by the red beds, or because of limited geographical range during the same portion of time, is not evident from the facts at hand. As was pointed out in Bull. U. S. Geol. Survey No. 41, *Athyris angelica* is a prevailing species in the upper Chemung horizons of the Genesee Valley sections. In the survey of that region, *Strophonella cælata* was not discovered. But it is also to be noted that *Spirifer disjunctus* is a very common species in the typical Chemung fauna of western New York, and is there frequently associated with *Athyris*. It is not a very frequently occurring species in the typical Chemung beds of the more eastern sections, although it is very abundant in some zones.

The faunal indications of these Tioga County sections therefore favor the view that both the *Strophonella* and *Athyris* zones are well up in the Chemung formation; and, according to the opinion of the writer, are to be correlated stratigraphically with beds occupying the higher hilltops of the Waverly quadrangle, above the fossiliferous zones of the cliffs along Chemung River at Chemung Narrows and Waverly. Fuller collections of fossils from this and neighboring regions will throw light upon this problem.

COMMENTS ON THE CORRELATION OF THE SECTIONS OF BRADFORD AND TIOGA COUNTIES, PA.

By H. S. Williams.

In Pl. IV the several sections of Bradford and Tioga counties, measured by E. M. Kindle, the faunules of which are discussed in the previous pages, are arranged according to the evidence furnished by the contained fossils. Placed to the left of them is the section (generalized) of the Tioga folio as prepared by M. L. Fuller. The sections are all drawn to same scale, and the lower ones are correlated according to contained fossils, while those at the top of the series are correlated by the beds supposed to represent the Mauch Chunk and Sharon formations.



SECTIONS IN BRADFORD AND TIOGA COUNTIES, PA.

The three sections on the right represent a single measured set of beds near one another. The gap which is covered in the valley of Towanda Creek is estimated from the dip of the beds on each side, so that it is believed the total length of the section is approximately correct. In this section 1,487 feet are referred to the Chemung formation, the Chemung species prevailing to the top. The top of the Franklindale calcareous beds is 400 feet down in the Chemung, and its thickness is 160 feet in the Gulf Brook section (zones 75 to 58). From the top of the Chemung to an arbitrary line drawn between the Cattaraugus and Oswayo (at 1455 C8) is 653 feet; this is the estimated thickness of the Cattaraugus for this section.

The correlation of the Towanda Narrows section (1456 A) with the Gulf Brook (Leroy) section (1455 A) is made by means of the upper calcareous zone of the Franklindale limestone beds—1456 A17 and 20, being correlated with 1455 A73 and 75. As both of these sections are based on detailed measurements of the individual zones, this places zone 1456 A40, which contains an unmistakable Chemung faunule, a little over 1,700 feet above zone 1455 A8, which also holds a distinctly Chemung faunule, and over 250 (top 263) feet above the arbitrary line drawn at top of the Chemung formation. This arbitrary line is drawn as being approximately the place of beginning of typical Catskill red sedimentation; below, for several hundred feet, appear occasionally dull reddish and purplish beds, but no considerable bright red sandstones. It is not imagined that this upper zone of Chemung species, 1456 A40, is in reality the highest place of occurrence of this fauna. Further search will be likely to show species of this fauna as long as the marine conditions were persistent in the neighborhood of this section. The stopping of the marine Chemung invertebrates is supposed to have been occasioned by a change of local conditions which was associated with deposition of the red beds, and locally drove out the species from the region, but did not destroy them. This interpretation seems best to explain the irregularity of the line of separation between Chemung and Cattaraugus.

The interval between the top of zone 1456 A40 of the Towanda Narrows section and the observed base of the South Mountain section on the opposite side of the Towanda Creek Valley is estimated to be about 100 feet. The rocks are all covered and the estimate is based on dip and actual barometric determination of altitude of the several outcrops. This estimate may be too great or too little, but the measuresments of the sections otherwise are based upon actual distances from zone to zone as measured at the outcrops.

The red beds prevail in the observed outcrops from the base of the South Mountain section to zone 1455 C26, which is correlated with the Armenia limestone lentil of the section on Armenia Mountain (1458 B29). Nevertheless, as Kindle states on a previous page, the red

outcrops are less conspicuous in the upper part of the section than below the fish bed (1455 C8) at the the top of which is abitrarily drawn the division line between the Cattaraugus and Oswayo, thus giving to the Cattaraugus a thickness of 653 feet, as before stated.

The Armenia section (1458) is made up of prevailingly red beds up to the base of 1458 B21. This is a green, coarse, heavy-bedded micaceous sandstone with some plant remains, and divided by a few shale bands and is 35 feet thick. Above this to the top of the section the beds are green and gray, except zone B26, which is a soft red shale 18 feet thick, situated 25 feet below the Armenia limestone lentil (1458 B29). This gives about 100 feet of gray beds below the Armenia limestone lentil in western Bradford County. The upper part of the Tioga section, 4 miles east of Tioga (1460 A), shows a coarse white sandstone with angular quartz pebbles, of 20 feet thickness, at the top. This is called the Sharon conglomerate member of the Pottsville conglomerate by Fuller, in the Elkland-Tioga folio. There seems no reason to doubt the general equivalency of the conglomerate (1455 C31) with this upper zone of the Tioga section (1460A). But the correlation of the horizon of this and the immediately underlying beds is in this paper made on basis of determination and nomenclature already published in the Elkland-Tioga folio, without attempting to discuss the validity of that determination. On similar ground the uppermost cross-bedded sandstone of the Armenia section (1458 B31) is called Sharon conglomerate in this paper. The Armenia limestone lentil of the Tioga section (1460 A52) is a zone 10 feet in thickness 46 feet below the sandstone and contains fish teeth and lumps of shale. A red shale zone 10 feet thick is separated from the base of the latter by 30 feet of gray beds.

On the basis of red beds and fish remains the equivalent of the Catskill of early literature might be carried down at least to the base of the Franklindale limestone member, 927 feet above the base of the Gulf Brook section; but on the basis of marine invertebrate fossils the Chemung formation runs up to at least zone 1456 A40, or to 1,750 feet above that base, a difference of 823 feet thickness of strata for the overlapping of these two conditions.

This interval may be called Chemung, Cattaraugus, or transition beds of Chemung, Catskill, or Chemung-Catskill, according to the prejudice of the authors. Whatever name is applied to the various parts of the section it is clear to the paleontologist that as one passes from eastern Pennsylvania and New York westward across the sections, the place of first appearance of the red beds is at a later stage of evolution of the faunas. In any particular locality the length of the interval from the first appearance of the red beds to the final deposition of the marine Chemung faunas was probably determined by the degree of persistence with which the changed conditions marked

by the red deposits prevailed at that spot. The evidence at hand points to a greater persistence of the red sedimentation in the eastern than in the western sections. But only as the time horizons are determined by the fossils is it possible to correlate equivalency of horizons across the regions which thus differ in the character of the sediments laid down. The application of formational names therefore on the basis of likeness in the character of the sediments, which are known to geographically differ, must necessarily be regarded as not significant of actually synchronous time divisions.

GENERAL INDEX.

INDEX TO PALEONTOLOGIC NAMES.

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